EMPLOYEE TRAVEL AT THE DALLAS/FORT WORTH

REGIONAL AIRPORT

APPROVED

[redacted]

To my wife and parents.

EMPLOYEE TRAVEL AT THE DALLAS/FORT WORTH REGIONAL AIRPORT

by

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B. S. in Civil Engineering

THESIS

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Special thanks to my wife, my great support, and my parents.

ABSTRACT

This thesis presents an analysis of data that were obtained from the Employee Travel Survey made at the Dallas/Fort Worth Regional Airport (DFW) in May 1975 and a methodology for estimating DFW employee vehicular volumes arriving at or leaving the airport in a given time interval. From the survey information, an analysis is made of employee characteristics for all the DFW employees. This is followed by a comparison of employee characteristics according to whether or not they previously worked at Love Field Airport in Dallas.

Theoretical distributions are developed for the period between the times that the employees' work shifts start and end and the actual time that employees arrive at or leave the airport relative to those starting and ending times. Different theoretical distributions are obtained for different periods of the day. Finally, a model is developed for estimating employee vehicular volumes from the work shift times (starting or ending) and the number of employees on each work shift. Estimates from the model were found to compare favorably with actual counts of employee vehicles made during the survey.

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CHAPTER I. INTRODUCTION

The work presented in this thesis is part of a project undertaken under the auspices of the Council for Advanced Transportation Studies at The University of Texas at Austin. The project is sponsored by the Office of University Research of the U. S. Department of Transportation. The study staff consisted of two principal investigators, Dr. William J. Dunlay, Jr. of Civil Engineering and Dr. Pat Burnett of Geography, plus various research associates, graduate research students (of which the author was one), and undergraduate students.

Objectives of Study

The objective of the research described in this thesis is to analyze part of the data obtained from the Dallas-Fort Worth Airport (DFW) employee survey conducted in May 1975 (Ref. 4). The analysis will consist of a comparison of DFW employees according to whether or not they previously worked at Love Field Airport in Dallas and an analysis of the times that employees arrived at or left the airport relative to work shift starting or ending times. Based on this latter analysis, a methodology is developed for estimating the number of DFW employee vehicles that can be expected to enter and leave the airport in any given time interval.

Scope and Limitations

In the comparison of DFW employees according to whether or not they used to work at Love Field, a general analysis is made of all those characteristics for which both subsets of employees presented enough information in the above mentioned survey. In particular, the same analysis is made of both subsets and a comparison is made of the DFW employees who previously worked at Love Field and the current DFW employees who did not.

In the analysis of the time that employees arrive at or leave the airport relative to the starting and ending of their work shift, the

distributions of the interval between those two times are tested against known theoretical distributions. The number of candidate theoretical distributions is five, and the goodness-of-fit test used is the Kolmogorov-Smirnov Test (Refs. 1, 2, 5 and 13).

For the methodology developed to estimate the number of employees entering and leaving the airport in a given time interval, the required input includes the periods of the day to be considered, parameters of the above theoretical distributions for each period, the starting or ending time of each work shift, and the respective number of employees. The output is the number of employee vehicles entering or leaving the airport for any given time period.

CHAPTER II. PREVIOUS RESEARCH

The results of past airport employee travel surveys have not been widely published. References which discuss this matter are quite limited. In most of the references concerned with the study of airport access traffic, the influence of the airport employees is mentioned, but how this influence is distributed in time is almost never described or modeled.

John Robinson and Peter Nordie (Ref. 12) present an origin/destination survey of Washington National Airport. In the employee survey part of that study the following procedures were followed:

1. Organizations having more that 75 employees were contacted personally. From an alphabetical listing of all employees of these organizations a sample consisting of every eighth person was selected, and a weekly record of travel patterns was obtained for that sample.
2. For organizations with less than 75 employees, questionnaires were sent to the organizations by mail with the instructions to be followed in selecting employees for the sample.
3. The information obtained from the employee survey included:
   a) Work hours
   b) Home address
   c) Type of vehicle
   d) Automobile occupancy
   e) Trip time (from and to the airport)
   f) Attitude toward trip time, i.e., feeling about the trip time.

Only summary comments about the results of the questions asked in the employee survey were presented in the reference 12.

Merrit Chance (Ref. 3) presents a study as to how the different users (of whom employees are one category) of airport access highways create ground transportation problems. In the section called "Daily Distribution of Air Passengers, Employees and Travel Related Visitors," several graphs that give some indication of the daily movement of people

at six airports, which are San Francisco, Washington National, Dulles, Friendship, Los Angeles, and London Heathrow, are presented. It is quite obvious that the percentage of volume represented by daily employees in this study was derived deterministically from the starting and ending work shift times. No references about the actual time distribution of airport employees arriving at or leaving the airport were found.

CHAPTER III. EMPLOYEE TRAVEL SURVEY

In order to investigate the travel habits of employees at the DFW airport, a travel survey was conducted by Dunlay, et al. (Ref. 4). In this survey, forms for the written, self-executed, type of questionnaire were distributed to more than 13,000 employees. The rate of response of completed questionnaires was 24 percent. Presently there are 13,368 employees at the Dallas/Fort Worth Airport. Table 3.1 shows the division of these employees by employer category.

The Survey Form

The employee survey form consisted of a short introductory paragraph followed by eleven questions (Fig. 3.1). The first question was to determine each employee's present home address, allowing the option of answering either by street address or by the nearest intersection. This option was designed to allow the response to be less personal and to encourage a response from persons who might be reluctant to give their address.

The next two questions dealt with how an employee perceives the distance and travel time between his home and DFW, and also between his home and Dallas Love Field. The answers to these questions can be compared with the true distances and travel times (Ref. 11).

Question number four asked the employee to indicate the type of vehicle he uses in his work trip. This was straightforward, and all reasonable alternatives were included in the check list.

The next topic of interest, question five, was whether the employee worked at Love Field before DFW opened. If a change of residence occurred because of the shift to the DFW airport, this was noted in Part B of the question. The respondent's old address was also obtained in Part C of the same question. It was hypothesized that the decision to move should be related to the actual travel time and distance between DFW and the respondent's old home. The employee was also asked to indicate the mode of transportation he used in his work trips to Love Field.

TABLE 3.1. EMPLOYEES BY CATEGORY OF EMPLOYER

EMPLOYER CATEGORY	NO. OF EMPLOYEES
Airlines	9,126
Air Cargo (1)	382
Air Mail Facility	350
Airport Marina Hotel	250
Allied Aviation Company	95
APCOA (Airport Parking Control)	135
DFW Airport Board	480
Federal Aviation Administration	135
Food Service	1,406
General Telephone Company	43
L.T.V. Airtrans	135
Maintenance (2)	284
Rent-A-Car Firms	268
Security (2)	120
Other	159
TOTAL	13,368

Source: Central Offices at DFW of the Employers and the DFW Airport Board.

(1) Excluding Airlines with Airfreight

(2) Excluding DFW Airport Board (Airport Police)

DALLAS / FORT WORTH AIRPORT
EMPLOYEE TRAVEL SURVEY

Dear DFW Employees:

This survey is being conducted for the purpose of increasing our knowledge of airport-related travel.

Information from these questionnaires will be used to prepare plans and programs for the future development of transportation services to the DFW Airport so we can provide you with the best possible service.

Please take a few minutes to fill out the following questions and give the form to your supervisor.

Thank you.

1. WHAT IS YOUR PRESENT STREET ADDRESS?

_____
(Street No.) (Street name) (city or Town) (Zip)

OR

_____
(Nearest Street Intersection) (City or Town) (Zip)

2. YOUR TRAVEL DISTANCE (PLEASE ESTIMATE)

A. Approximately how many miles long would you guess your total trip to or from the airport to be?

About _____miles.

B. How many miles would your trip be to the old airport, Dallas Love Field? About _____miles

3. YOUR TRAVEL TIME (PLEASE ESTIMATE)

A. Approximately how many minutes does your total trip to or from the airport take?

About _____minutes.

B. How many minutes would a trip to Love Field take? About _____minutes.

4. TYPE OF VEHICLE TAKEN TO AND FROM WORK:

___Driving my own vehicle ___Taxi

___Riding in a carpool ___SURTRAN

___Being dropped off by someone ___Other (Please specify)_____

PLEASE DO NOT MARK IN THIS BOX.

1 2 3 4

5 6 7

8 9

10 11

12 13

14 15

16

Figure 3.1. Employee Survey Form

5. YOUR PREVIOUS AIRPORT EMPLOYMENT:

A. Did you work at Dallas Love Field before the opening of the new Dallas-Fort Worth Regional Airport? _____ Yes _____ No

B. IF YES, have you changed your place of residence or do you plan to change because of your shift to the new airport? _____ Yes _____ No
If you have moved, what was your previous street address?

_____
(Street No.) (Street Name) (City or Town) (Zip)

OR

_____
(Nearest Street Intersection) (City or Town) (Zip)

C. Type of vehicle taken to Love Field:

___Driving my own vehicle ___Taxi

___Riding in a carpool ___Public bus

___Being dropped off by someone ___Other (Please specify) _____

6 TIME THAT YOU ARRIVE AND LEAVE WORK:

A. What time did you arrive at the airport TODAY?_____ A.M. P.M.

B. What time did your work shift start TODAY?_____ A.M. P.M.

C. What time will you get off work TODAY?_____ A.M. P.M.

D. What time will you leave the airport TODAY?_____ A.M. P.M.

7. FREQUENCY OF YOUR TRAVEL:

Please check the days of the week you work at the airport.

___Sunday ___Tuesday ___Thursday ___Saturday

___Monday ___Wednesday ___Friday

8. YOU ARE: ___Male ___Female

9. YOUR AGE: (PLEASE CHECK ONE)

___Under 21 ___35-44 ___55-64

___21-34 ___45-54 ___Over 65

10. YOUR OCCUPATION: (PLEASE CHECK ONE)

_____Professional _____Craftsman, Foreman _____Other Labor

_____Clerical _____Technician/Operator _____Service (Please check one)

_____Sales _____Maintenance food/airline/custodian

11. YOUR FAMILY INCOME IS: (PLEASE CHECK ONE)

_____Under $6,500 _____$13,000 - $20,000 _____$26,000 - $32,000

_____$6,500 - $13,000 _____$20,000 - $26,000 _____Over $32,000

17 | 18 | 19 20 21 22 | 23 24 25 | 26 | 27 28 29 30 | 31 32 33 34 | 35 36 37 38 | 39 40 41 42 | 43 44 45 46 | 47 46 49 | 50 | 51 | 52 53 | 54 | 55 56 57 58

Figure 3.1. (Continued)

The next two questions, number six and seven, were intended to provide a sample of the employee's "normal" work day in terms of the time when he began the shift, the number of hours worked, and the number of days per week that he worked. The sample size was assumed to be large enough to offset the effect of asking for starting and quitting times on one specific day.

The survey form ended with some requests for personal data. These can be used to relate the travel behavior of employees to standard, identifiable demographic characteristics, similar to those gathered in the U. S. Census. The age group brackets were designed to encompass standard phases of the personal and family life cycle. The occupational breakdown followed the guidelines of census data, but was simplified somewhat for the convenience of the respondent. The family income brackets shown on the survey form are the same as those used in the previous survey at Love Field by Alan M. Vorhees, Inc. in 1969, but were adjusted upward for inflation using the increase in the region's Consumer Price Index.

Survey Method

The distribution and collection of the employee survey forms proved to be a time-consuming task as seventy-one airport-related employers had to be contacted. The vast majority of survey forms were distributed through the mail. A letter of introduction was included which explained the purpose of the survey (Fig. 3.2). In addition, a set of detailed instructions was compiled for the employers, which suggested a particular distribution and collection procedure (Fig. 3.3). A few announcements of the study suitable for posting were also included in the packet of information sent to employers. The survey forms were distributed through the employee supervisors. Distribution and collection instructions for the supervisors were printed on the envelope which contained the forms (Fig. 3.4).

D

THE UNIVERSITY OF TEXAS AT AUSTIN
COUNCIL FOR ADVANCED TRANSPORTATION STUDIES
AUSTIN, TEXAS 78712

Suite 2.6 ECJ Hall
Phone (512) 471-4433

May 12, 1975

Dear Employer:

We wish to request your cooperation on a DFW Airport Travel Survey on Friday, May 16, 1975, being conducted by a project sponsored by the Council for Advanced Transportation Studies with the cooperation of the Dallas/Fort Worth Regional Airport Board. Separate surveys are being conducted of SURTRAN passengers, motorists, and DFW employees.

We are requesting your assistance both in notifying your employees of the survey and in distributing the forms to them this Friday, May 16. (Forms should be completed and returned as soon as possible.)

The following materials are enclosed:

1. An instruction sheet with a short form at the bottom to be returned to us.

2. Notices explaining the survey to your employees.

3. Sample copies of the survey forms. Packages of forms sufficient for the survey will be personally delivered to you on Thursday, May 15, 1975.

We hope that the enclosed instructions are clear and adequate. If you have any questions regarding them, please notify Mr. Michael Sganga, Director of Planning of the Dallas-Fort Worth Regional Airport Board, 214/574-3132, and he will pass your questions on to us so we can contact you ahead of time.

The data gathered in this survey can be used to improve traffic and transportation services for everyone who uses DFW. Your cooperation is essential to its success. Please be assured that we will strongly appreciate your assistance.

Sincerely,

Dr. William J. Dunlay, Jr.
Assistant Professor of Civil Engineering

rca

Figure 3.2. Introductory Letter to Employers.

DFW AIRPORT TRAVEL SURVEY

EMPLOYER:

M

Please take a few minutes of your time to help us conduct this survey of travel to and from the DFW Airport. Data gathered in this survey can be used to improve traffic and transportation services for everyone who uses DFW.

INSTRUCTIONS

1. Please notify your employees in advance of the DFW Airport Travel Survey by posting the enclosed notices as soon as you receive this material.
2. Please distribute the enclosed packages of survey forms to your supervisory employees on Friday, May 16, 1975. (Be sure to take enough forms for yourself and immediate staff.)
3. It is important that every full and part-time employee on every shift receive a form. Supervisors are requested to distribute the forms to the employees under their supervision.
4. Please encourage supervisors and employees to complete the form. It is important that they be completed and returned as soon as possible.
5. Supervisors are requested to collect the completed forms, put them back in the manila envelopes, and return them to the main office by 11:00 AM, Friday, May 23, 1975.
6. Please collect the packages of completed forms from your supervisors and place them in the enclosed large return-mail envelope.
7. Please complete the short form at the bottom of this sheet giving the total number of employees currently on your payroll. Enclose this sheet in the return-mail envelope containing the completed forms.
8. Mail the return-mail envelope containing the completed forms and this sheet back to us by Friday, May 23, 1975. This envelope is pre-addressed and postage is prepaid.

Thanks for your help!

COUNCIL FOR ADVANCED TRANSPORTATION STUDIES
UNIVERSITY OF TEXAS AT AUSTIN

Please complete and return this form.

Company or Agency_____

Number of Employees_____

Figure 3.3. Instructions to Employers.

DFW AIRPORT TRAVEL SURVEY

SUPERVISORS:

Please take a few minutes of your time to help us conduct this survey of travel to and from the DFW Airport. Data gathered in this survey can be used to improve traffic and transportation services for everyone who uses DFW.

INSTRUCTIONS

1. Please distribute the enclosed survey forms to the employees under your supervision on Friday, May 16, 1975.
2. Make sure every full and part-time employee on every shift receives a form. Don't forget yourself!
3. Please encourage employees to complete the form. It is important that they be completed as soon as possible.
4. Collect the completed forms back from your employees and put them back in the manila envelope.
5. Return the completed forms to your main office at DFW by 11:00 AM, Tuesday, May 20, 1975. They will be returned to us from there.
6. Send any "straggler" forms, received later, on to your main office at DFW.

THANKS FOR YOUR HELP!

Council for Advanced Transportation Studies
The University of Texas at Austin

Figure 3.4. Instructions to Supervisors.

Problems Encountered in Employee Survey

From the results examined so far, it appears that the overall design of the survey form was good, and that usable data were obtained. There was little or no confusion on most of the questions asked. However, the wording of some questions could be improved, and suggestions for this are given below.

Problems with the form itself involved wording, length, and the fact that the Airport Board had recently conducted a survey ot its own. Thus, the fact that some employees might have been irritated by the necessity to execute another survey form may have lowered the response rate.

The initial confusion in the employee survey was due to delays in delivering the packages of forms to the employers by the postal service. In some cases, the packages of forms were not delivered until the day they were supposed to be filled out. This allowed no time for employers to adequately organize their distribution effort. In addition, delays in some intra-airport communication channels resulted in management personnel receiving the forms as late as the following Monday or Tuesday, May 19 and 20. Since the instructions requested that employers and supervisors "...distribute the enclosed survey forms to the employees under your supervision on Friday, May 16..." some employers who received their forms after May 16 assumed that it was too late to distribute them. The project staff subsequently had to contact these employers and encourage them to distribute the forms to their employees.

In question one the zip code was requested as part of the address. This proved to be a valuable piece of information, as some respondents left out their city name but included their zip code.

A small number of respondents misinterpreted question two as asking for a round trip distance. This could have been avoided by specifying a one-way distance. Also, a few respondents may have misinterpreted question 2B as asking for the distance between DFW and Love Field since they were filling out the form at DFW. It was possible to spot-check these errors by the locations of the two airports relative to their homes.

Question four could be improved by asking for the vehicle taken "most often" or "usually," as several multiple responses were encountered.

Another troublesome question was the one that requested employees to classify themselves by occupation (professional, clerical, sales, craftsman/foreman, technician/operation, maintenance, other labor, service). It was deemed preferable to give the respondent a check list for this purpose, to avoid nebulous and illegible answers which would be difficult to interpret by the project staff. However, it turns out that the wording of such a list may also be conducive to misinterpretation by the respondent. In addition, a question of this type actually solicits the respondent's perceived self-classification. That this can produce problems has been recognized by the incongruities found between responses to this question vis-a-vis responses to related questions, e.g., a "clerical" worker with income "$26,000 - $32,000." The occupational breakdown used was selected in consultation with the North Central Texas Council of Governments which was doing a study of basic and non-basic industry in the Dallas/Fort Worth Region.

With regard to questions six and seven, some employees with rotating shifts only stated unspecifically that days and work shift time vary. Others specified that days and work shift time vary and included the work days and shift times at the time of the survey. Still others checked all the days of the week.

Concerning question number 10, two new job categories were created because of employee responses: "Rent-a-car" and "Hotel employees." Also, the percent of employees checking "Other Labor" was relatively high.

Sample Size

A total of 3,157 employee forms plus 84 late forms have been returned, which constitutes a 24 percent rate of return of the 13,368 forms distributed. Table 3.2 shows the number and percent of survey forms returned by type of employer. General Telephone Company, Airport Parking Control, and DFW Airport Board were the employer categories with the highest

TABLE 3.2. EMPLOYEE SAMPLE BY TYPE OF EMPLOYER CATEGORY

EMPLOYER CATEGORY	SAMPLE	PERCENT RETURNED
Airlines	1,211	13.3
Air Cargo (1)	70	18.3
Air Mail Facility	200	57.1
Airport Marina Hotel	171	48.4
Allied Aviation Company	0	0.0
APCOA (Airport Parking Control)	87	64.4
DFW Airport Board	294	61.2
Federal Aviation Administration	57	42.2
Food Service	283	20.1
General Telephone Company	31	72.1
L.T.V. Airtrans	29	21.5
Maintenance	94	33.1
Rent-a-Car Firms	126	47.0
Security (2)	19	15.83
Other	26	16.3
Unidentified	594	4.4
TOTAL	3,241	24.2

Source: Central Offices at DFW of the Employers and the DFW Airport Board.

(1) Excluding Airlines with Airfreight.

(2) Excluding DFW Airport Board (Airport Police)

rates of return (72.1%, 64.4%, and 61.2% respectively). On the other hand, Allied Aviation Company, the airlines , and security were the employer categories with the lowest percent rate of return (0%, 13.3% and 15.8% respectively).

CHAPTER IV. ANALYSIS OF DFW EMPLOYEE DATA

This chapter is divided into two major sections. The first section deals with the total sampled DFW employees and their residential location broken down by zone, city, type of vehicle used for work trip, occupation, income, age and sex. In the second section of the chapter, the same analysis and a comparison are made of the two subsets of employees at DFW, namely, those that used to work at Love Field airport before the opening of DFW, and those that did not.

The study area considered in this analysis is divided into zones designated by the North Central Texas Council of Governments (NCTCOG), giving emphasis to the so-called Intensive Study Area (ISA), which covers primarily Tarrant and Dallas counties (Fig. 4.1). Later in this analysis, the ISA zones are grouped at the city level (Fig. 4.2).

Total Sampled by DFW Employees

DFW Employees by Zone. Figure 4.3 shows the distribution of residential location of DFW employees disaggregated by zones inside of the study area. Table A.1 in Appendix A shows the frequency and the percent of the sample in each zone of the study area.

There are two pertinent observations to be made. The first is the wide dispersion of small percentages of employees on the one hand, and the single concentration of 14.4 percent in five zones near the airport (zones 350, 368, 374, 375 and 380) on the other. Note that the maximum percent in any zone is only 5. Therefore, the sample distribution by zone is considered to be too small and an aggregation of the zones into bigger areas is desirable.

DFW Employee Distribution by City. One way to aggregate the zones is at the city level. This produces a clear idea of how the employees are distribtued in the study area. Table 4.1A and Table 4.1B show the frequency and percent of the sample of employees for the cities inside and outside the intensive study area, respectively. Figure 4.4 shows graphically that the city of Dallas has the largest single portion of

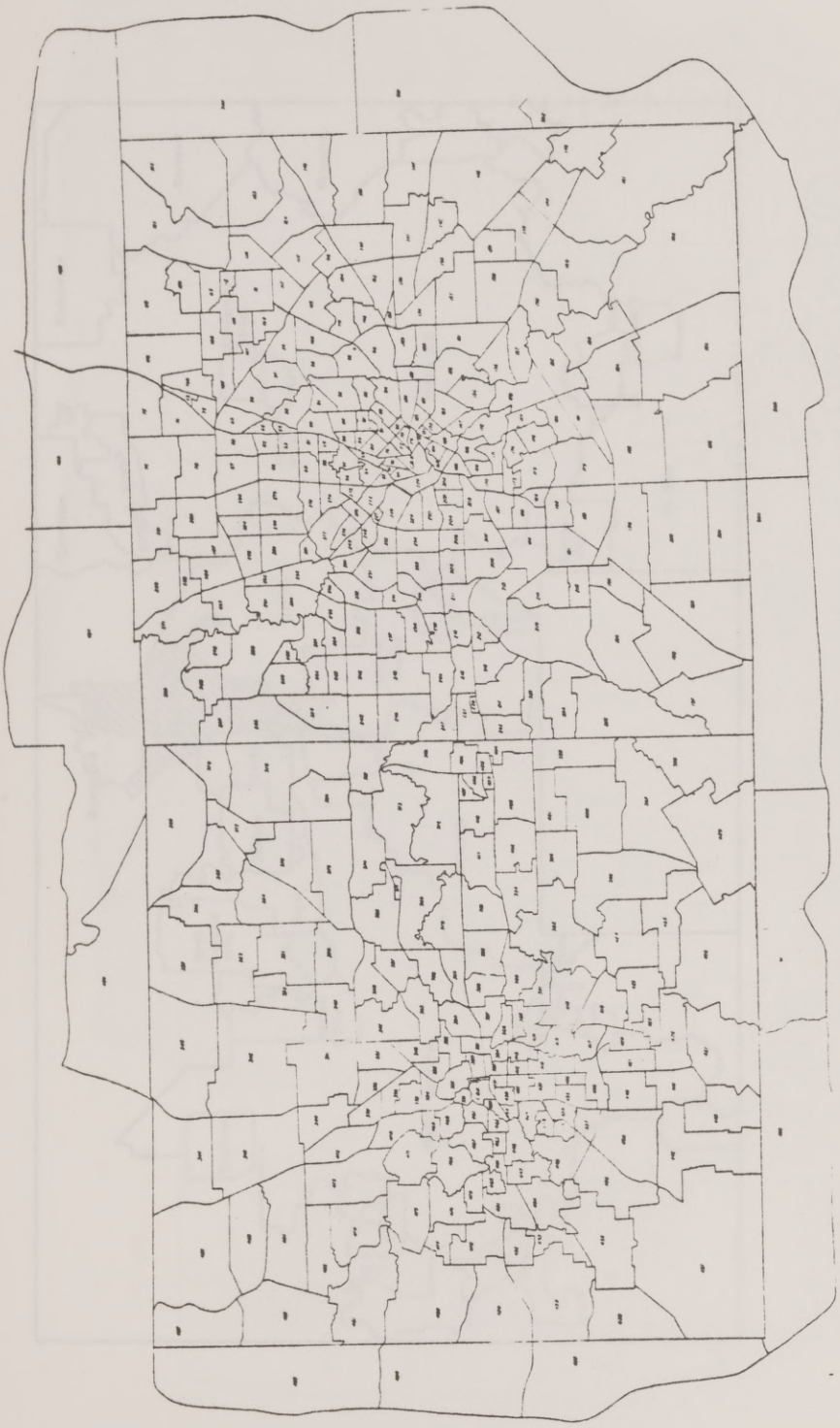


Figure 4.1. Regional Analysis Area Designations.

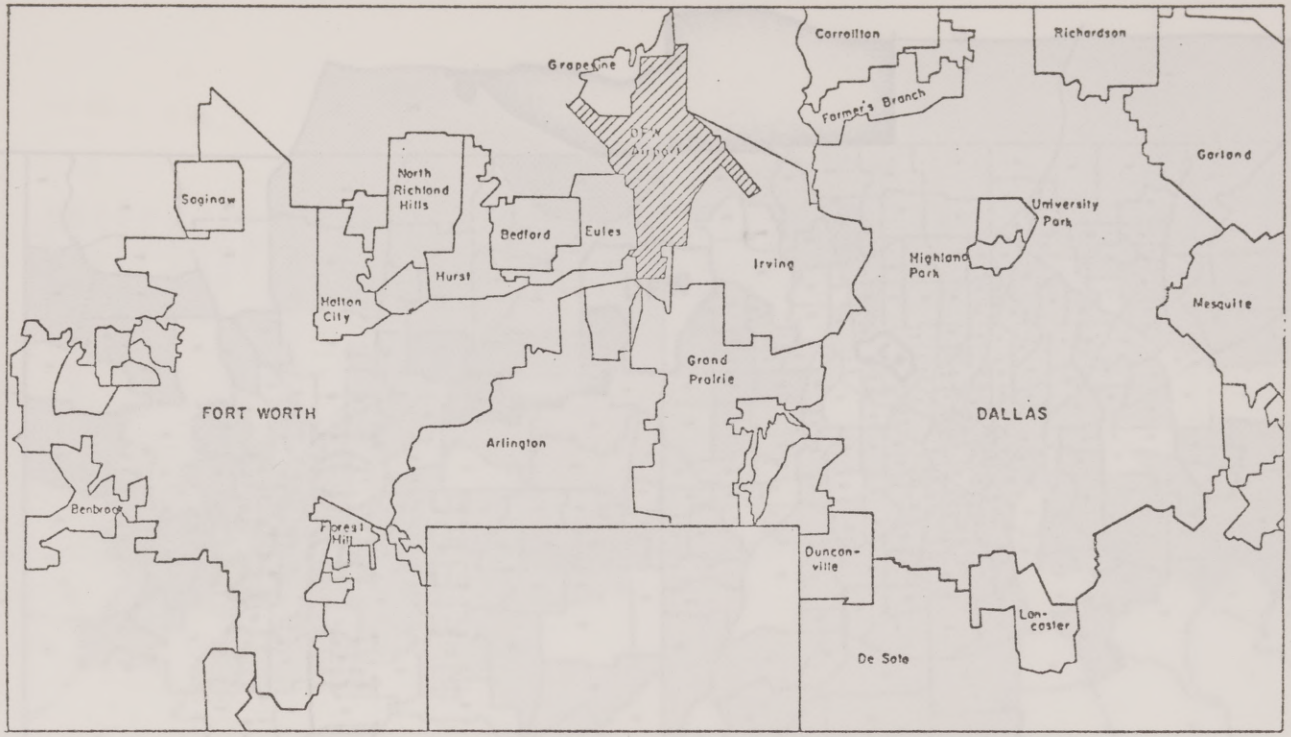


Figure 4.2. Cities Inside the Intensive Study Area.

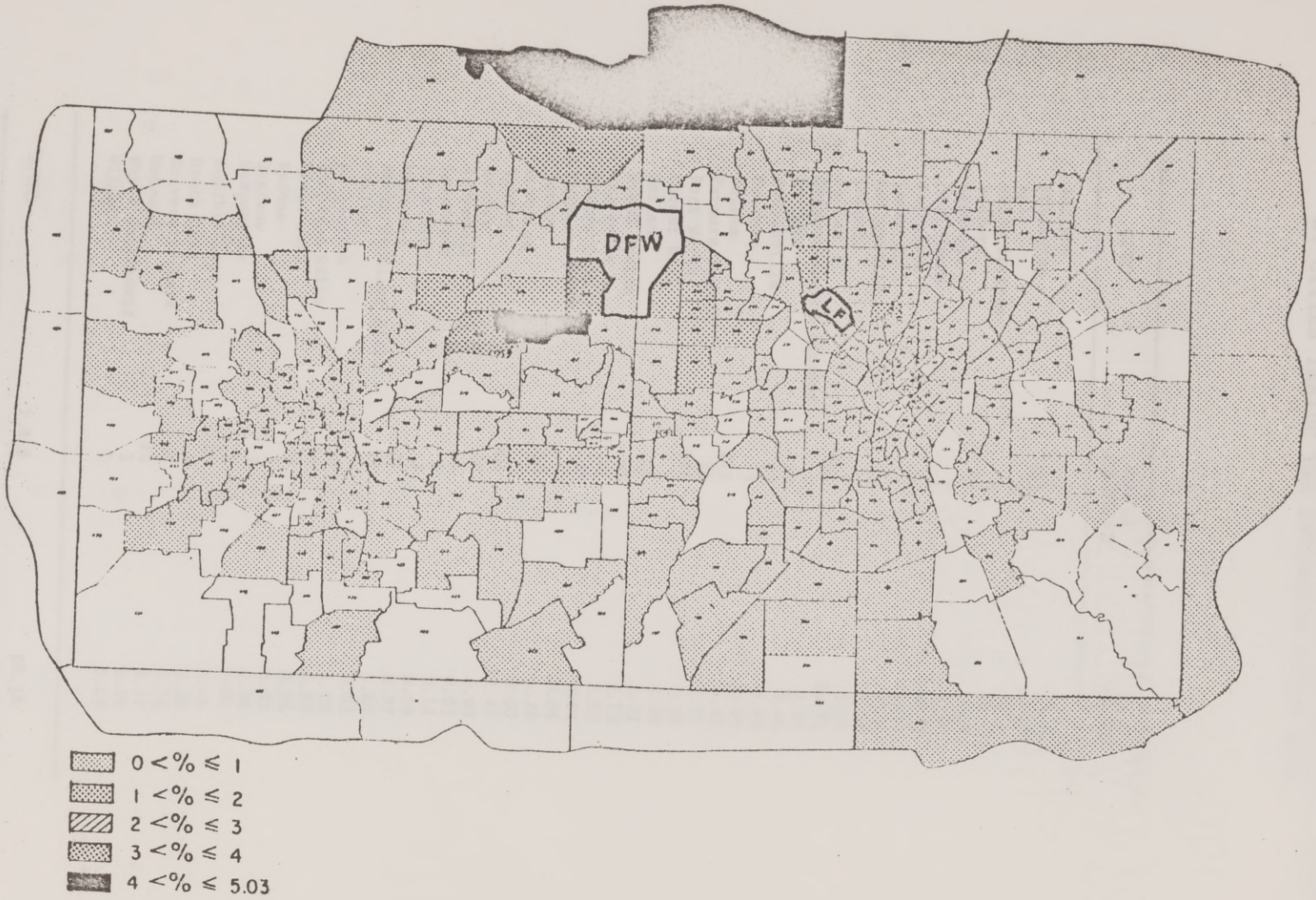


Figure 4.3. Zonal Distribution of DFW Employees

TABLE 4.1A. DISTRIBUTION OF DFW EMPLOYEE RESIDENTIAL LOCATION BY CITIES INSIDE THE INTENSIVE STUDY AREA

CITY	SAMPLE FREQUENCY	PERCENT
Addison	7	0.22
Arlington	233	7.19
Azle	3	0.09
Balch Springs	4	0.12
Bedford	93	2.87
Benbrook	3	0.09
Blue Mound	4	0.12
Carrolton	74	2.28
Cedar Hill	5	0.15
Colleyville	28	0.86
Coppell	8	0.25
Dallas	801	24.71
Dalworthington Gardens	1	0.03
De Soto	13	0.40
Cuncanville	13	0.40
Everman	3	0.09
Euless	215	6.63
Farmers Branch	56	1.73
Fort Worth	257	7.93
Forest Hill	3	0.09
Garland	49	1.51
Grand Praire	88	2.72
Grapevine	93	2.87
Haltom City	20	0.62
Highland Park	2	0.06
Hurst	138	4.26
Hutchins	1	0.03
Irving	404	12.47
Keller	30	0.93
Kennedale	1	0.03
Lancaster	4	0.12
Mansfiled	3	0.09
Mesquite	25	0.77
North Richland Hills	59	1.82
Pantego	1	0.03
Richardson	33	1.02
Richland Hills	19	0.59
River Oaks	2	0.06
Sachse	1	0.03
Saginaw	2	0.06
Seagoville	1	0.03
Smithville	15	0.46
South Lake	9	0.28
University Park	18	0.56
Watauga	12	0.37
White Settlement	3	0.09
Wilmer	1	0.03
TOTAL	2,858	88.18

TABLE 4.1B. DISTRIBUTION OF EMPLOYEE RESIDENTIAL LOCATION BY CITIES OUTSIDE THE INTENSIVE STUDY AREA

CITY	SAMPLE FREQUENCY	% OF TOTAL
Allen	2	0.06
Alvord	1	0.03
Argyle	7	0.22
Aubrey	1	0.03
Blue Ridge	2	0.06
Bonham	1	0.03
Bowie	1	0.03
Boyd	6	0.19
Bridgeport	4	0.12
Celina	2	0.06
Celeste	1	0.03
Cleburne	1	0.03
Clifton	1	0.03
Collinsville	1	0.03
Conroe	1	0.03
Decature	1,	0.03
Denton	31	0.96
Elmo	2	0.06
Ennis	2	0.06
Fairfield	1	0.03
Farmesville	1	0.03
Ferris	2	0.06
Flower Mound	2	0.06
Frisco	8	0.25
Gainsville	1	0.03
Granbury	1	0.03
Gordon	1	0.03
Greenville	1	0.03
Joshua	2	0.06
Justin	4	0.12
Highland Village	1	0.03
Kerns	1	0.03
Lake Dallas	6	0.19
Little Elm	1	0.03
Lewisville	113	3.49
Mabank	3	0.09
McKinney	9	0.28
Midlothian	1	0.03
Nevada	1	0.03
Nocona	1	0.03
Paradise	1	0.03
Plano	26	0.80
Pilot Point	2	0.06
Ponder	2	0.06
Poolville	1	0.03
Quinlan	1	0.03
RedOak	2	0.06
Rhome	1	0.03
Roanoke	30	0.92
Rockwall	3	0.09
San Marcos	1	0.03
Sanger	3	0.09
Sunset	1	0.03
Tioga	1	0.03
Valley View	2	0.06
Weatherford	3	0.09
Waxahachie	5	0.16
Wills Point	1	0.03
Whitewright	1	0.03
Wylie	4	0.12
TOTAL	320	9.87

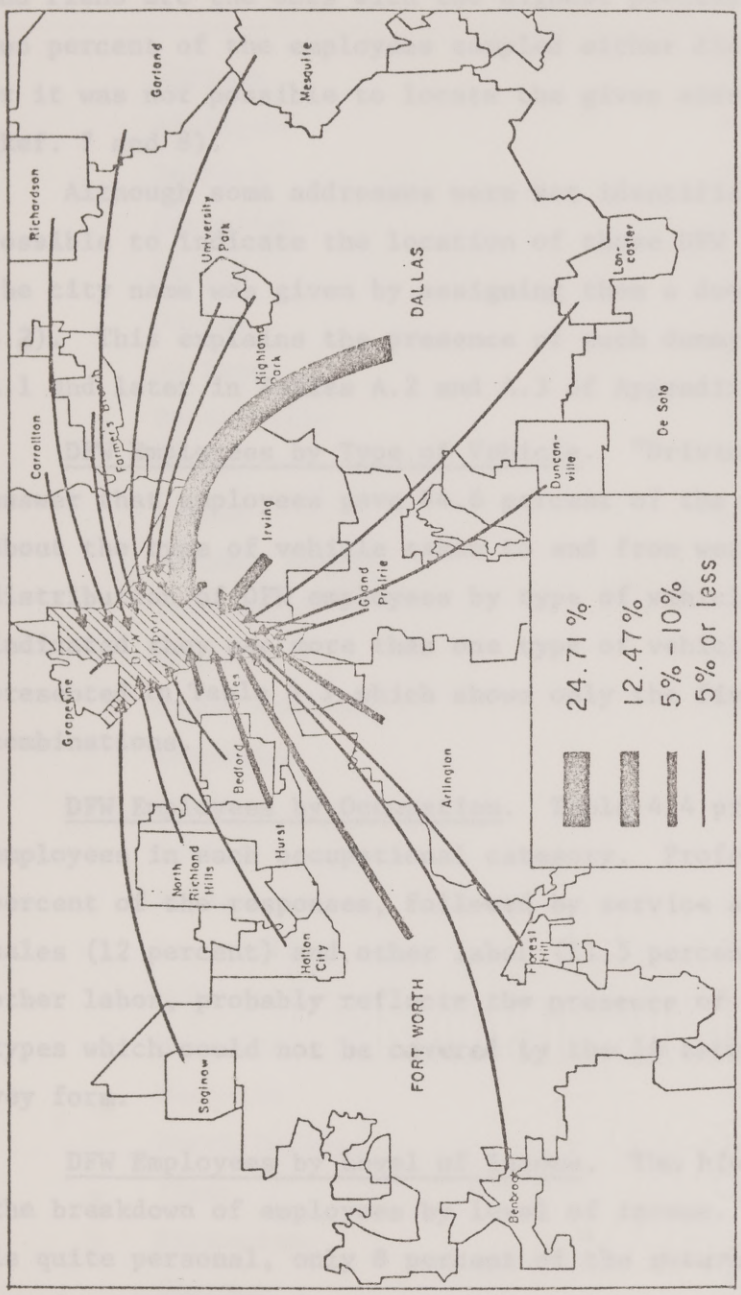


Figure 4.4. Distribution of DFW Employees by Cities Inside the Intensive Study Area.

DFW employees with 24.7 percent. In comparision, Irving has 12.5 percent of the total employees sampled--half that of Dallas despite its smaller population. Of the cities outside the ISA, Lewisville, Denton, Roanoke and Plano are the ones with the highest percent of employee residences. Two percent of the employees sampled either did not give their address or it was not possible to locate the given address on the reference maps (Ref. 7 and 8).

Although some addresses were not identifiable by zone, it was possible to indicate the location of those DFW employees for which only the city name was given by assigning them a dummy zone number (see Table 4.2). This explains the presence of such dummy zone numbers in Table A.1 and later in Tables A.2 and A.3 of Appendix A.

DFW Employees by Type of Vehicle. "Driving my own vehicle," was the answer that employees gave 84.6 percent of the time when they were asked about the type of vehicle taken to and from work. Figure 4.5 shows the distribution of DFW employees by type of vehicle. Data on employees who indicated they use more than one type of vehicle in their work trip are presented in Table 4.3, which shows only the five most frequently given combinations.

DFW Employees by Occupation. Table 4.4 presents the percent of employees in each occupational category. Professionals account for 30.5 percent of the responses, followed by service airlines (15.1 percent), sales (12 percent) and other labor (11.5 percent). The last category, other labor, probably reflects the presence of a large variety of work types which could not be covered by the 10 categories named on the survey form.

DFW Employees by Level of Income. The histogram in Fig. 4.6 shows the breakdown of employees by level of income. Although this question is quite personal, only 8 percent of the returned survey forms did not mention the family income.

DFW Employees by Age and Sex. The range of 21 to 44 years accounts for the highest percent of employees (75 percent) with 49.3 percent

TABLE 4.2. ZONE NUMBERS FOR THOSE EMPLOYEES WHO DID NOT GIVE A COMPLETE ADDRESS BUT DID GIVE THE CITY

CITY	ZONE
Addison	729
Arlington	704
Bedford	714
Carrolton	708
Dallas	700
Denton	715
De Soto	737
Duncanville	713
Ennis	735
Euless	710
Farmers Branch	709
Fort Worth	701
Garland	706
Grand Prairie	703
Grapevine	712
Hurst	711
Irving	702
Keller	740
Lewisville	730
McKinney	734
Mesquite	707
Mesquite	732
North Dallas	728
Plano	733
Richardson	705
Sherman	736
West Side Fort Worth	731

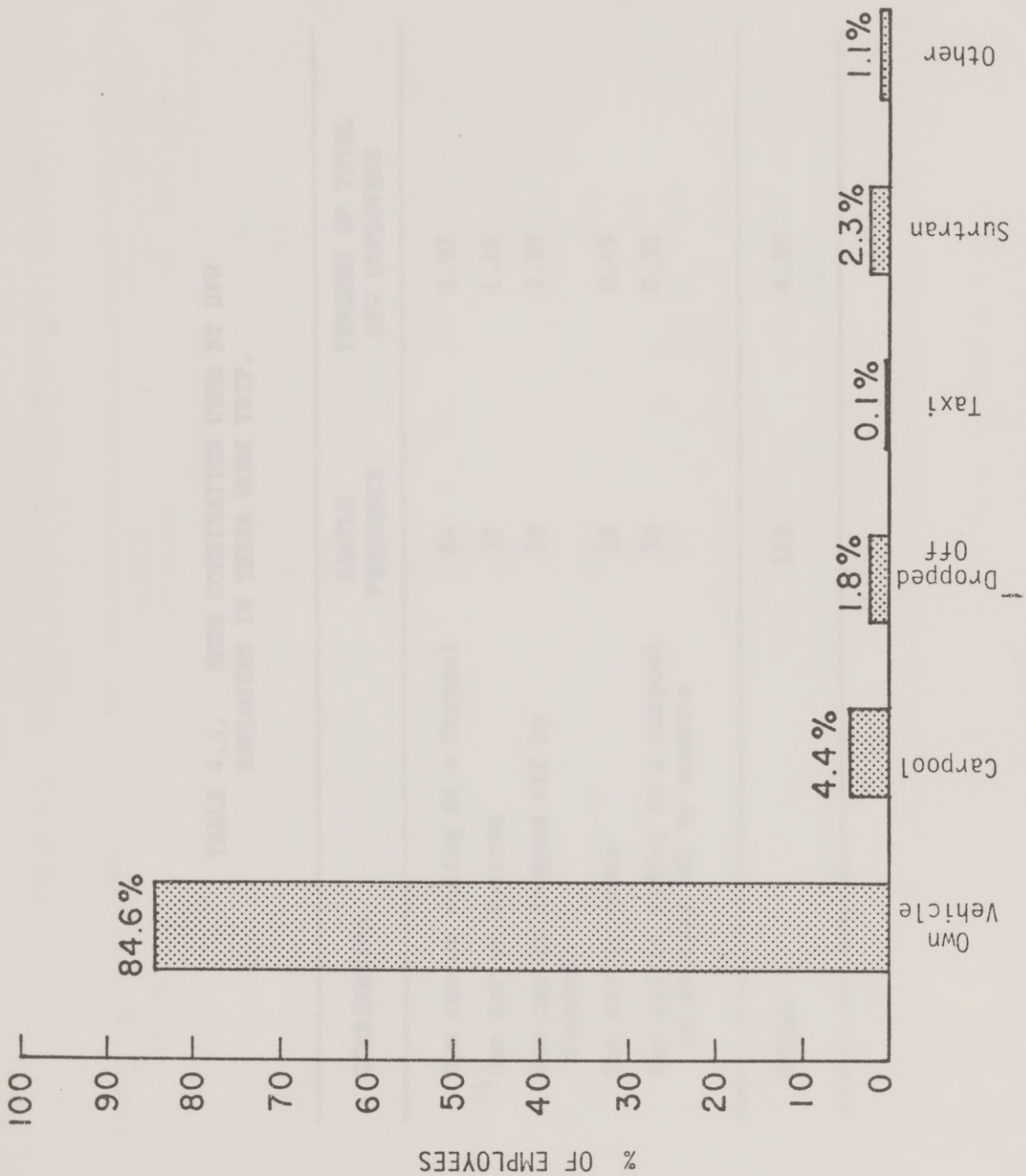


Figure 4.5. DFW Employees Work Travel Mode.

TABLE 4.3. MODE COMBINATION USED BY DFW EMPLOYEES IN THEIR WORK TRIP.

COMBINATION	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES
Own car or riding in a Carpool	64	1.97
Own car or Surtran	37	1.14
Own car or dropped off by someone	19	2.59
Own car or other	16	0.49
Own car or riding in a carpool or dropped off by someone	10	0.31
TOTAL	146	4.50

TABLE 4.4. PERCENT OF DFW EMPLOYEES BY TYPE OF WORK

OCCUPATION	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES
Professional	990	30.5
Clerical	389	12.0
Sales	180	5.6
Craftsman, Foreman	72	2.2
Technician/Operator	113	3.5
Maintenance	233	7.2
Other Labor	374	11.5
Service (Food)	188	5.8
Service (Airline)	491	15.1
Service (Custodian)	37	1.1
Rent-A-Car	29	0.9
Hotel Employee	32	1.0
No Response	113	3.5
TOTAL	3,241	100.00

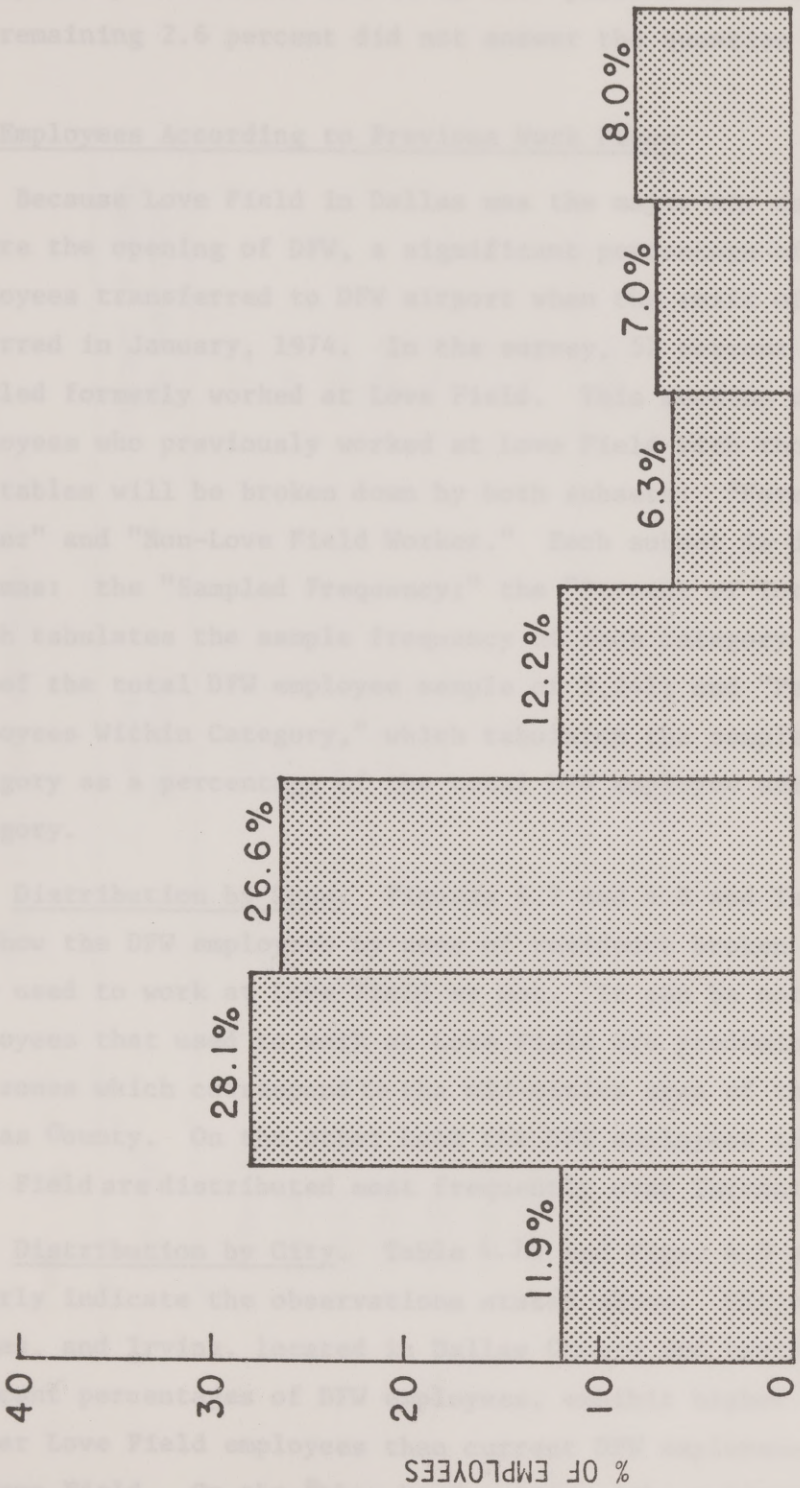


Figure 4.6. DFW Employees by Family Income.

between 21 and 34 years of age (see Table 4.5). The distribution of employees by sex turned out to be 63.3 percent males and 34.1 females. The remaining 2.6 percent did not answer the question (see Table 4.6).

DFW Employees According to Previous Work Place

Because Love Field in Dallas was the major air carrier airport before the opening of DFW, a significant percentage of former Love Field employees transferred to DFW airport when the shift of operations occurred in January, 1974. In the survey, 57 percent of the employees sampled formerly worked at Love Field. This section will compare DFW employees who previously worked at Love Field with those who did not. The tables will be broken down by both subsets: "Former Love Field Worker" and "Non-Love Field Worker." Each subset is divided into three columns: the "Sampled Frequency;" the "Percent of Total DFW Employees," which tabulates the sample frequency of each category label as a percentage of the total DFW employee sample of 3,241; and "Percent of DFW Employees Within Category," which tabulates the sample frequency of each category as a percentage of the total DFW employee sample in the same category.

Distribution by Zone. Figures 4.7 and 4.8 and Table A.2 of Appendix A, show the DFW employees by zone of residence broken down by whether they used to work at Love Field or not. It can be noted that those employees that used to work at Love Field are predominantly spread over the zones which correspond to the mid-cities area of the ISA and to Dallas County. On the other hand the DFW employees that did not work at Love Field are distributed most frequently over Tarrant County.

Distribution by City. Table 4.7A and Figs. 4.9 and 4.10 more clearly indicate the observations stated above. Cities like Carrolton, Dallas, and Irving, located in Dallas County and having relatively significant percentages of DFW employees, exhibit higher percentages of former Love Field employees than current DFW employees who did not work at Love Field. On the other hand, cities like Arlington, Bedford, Hurst, and Fort Worth, located in Tarrant County and having a relatively high

TABLE 4.5. DFW EMPLOYEES BY AGE

CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES
Under 21	251	7.7
21-34	1,599	49.3
35-44	773	23.9
45-54	432	13.3
55-64	138	4.3
Over 65	7	.2
No Response	41	1.3
TOTAL	3,241	100.0

TABLE 4.6. DFW EMPLOYEES BY SEX

CATEGORY	SAMPLE FREQUENCY	PERCENT
Male	2,052	63.3
Female	1,105	34.1
No Response	84	2.6

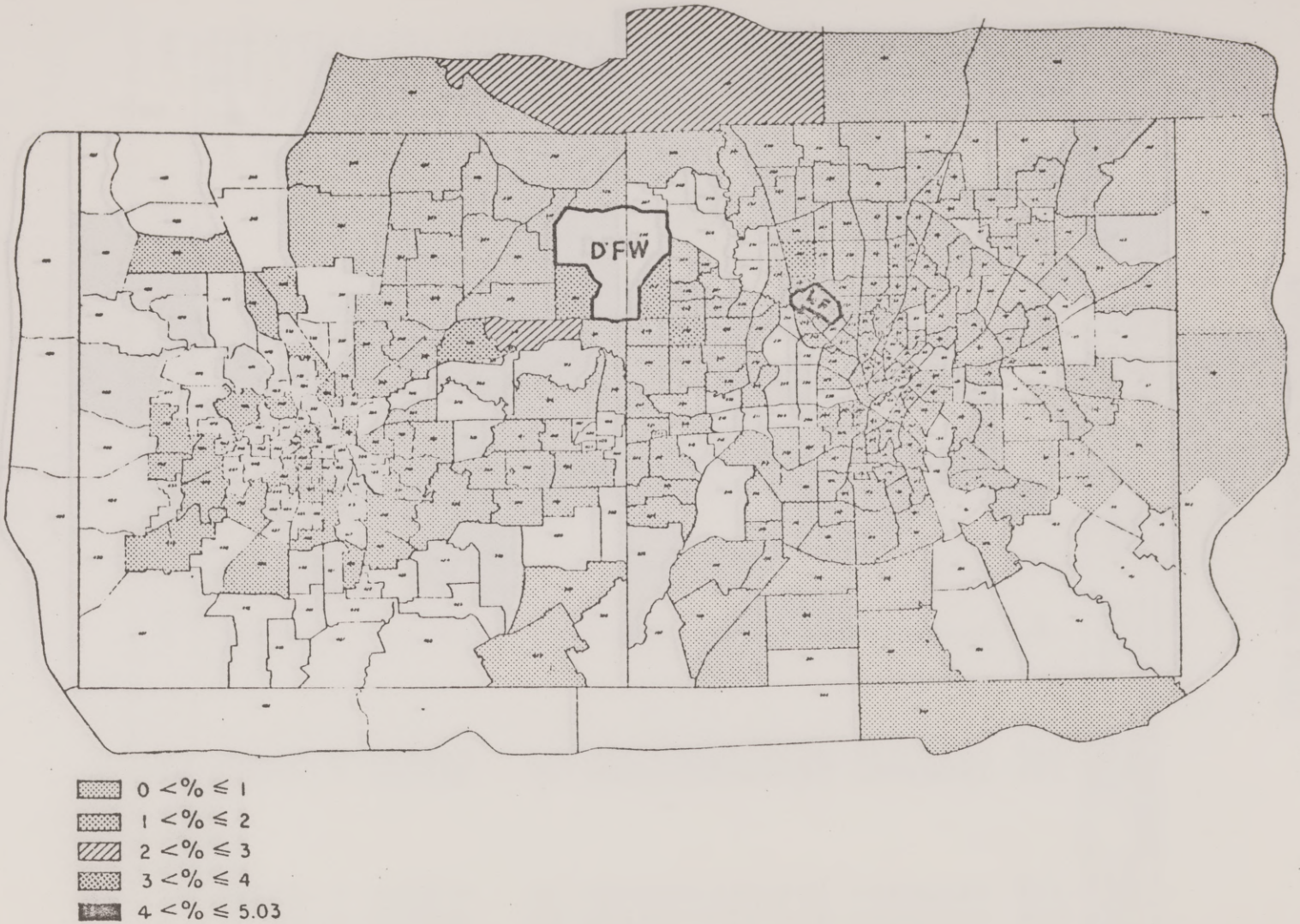


Figure 4.7. Zonal Distribution of DFW Employees Who Used to Work at Love Field Airport.

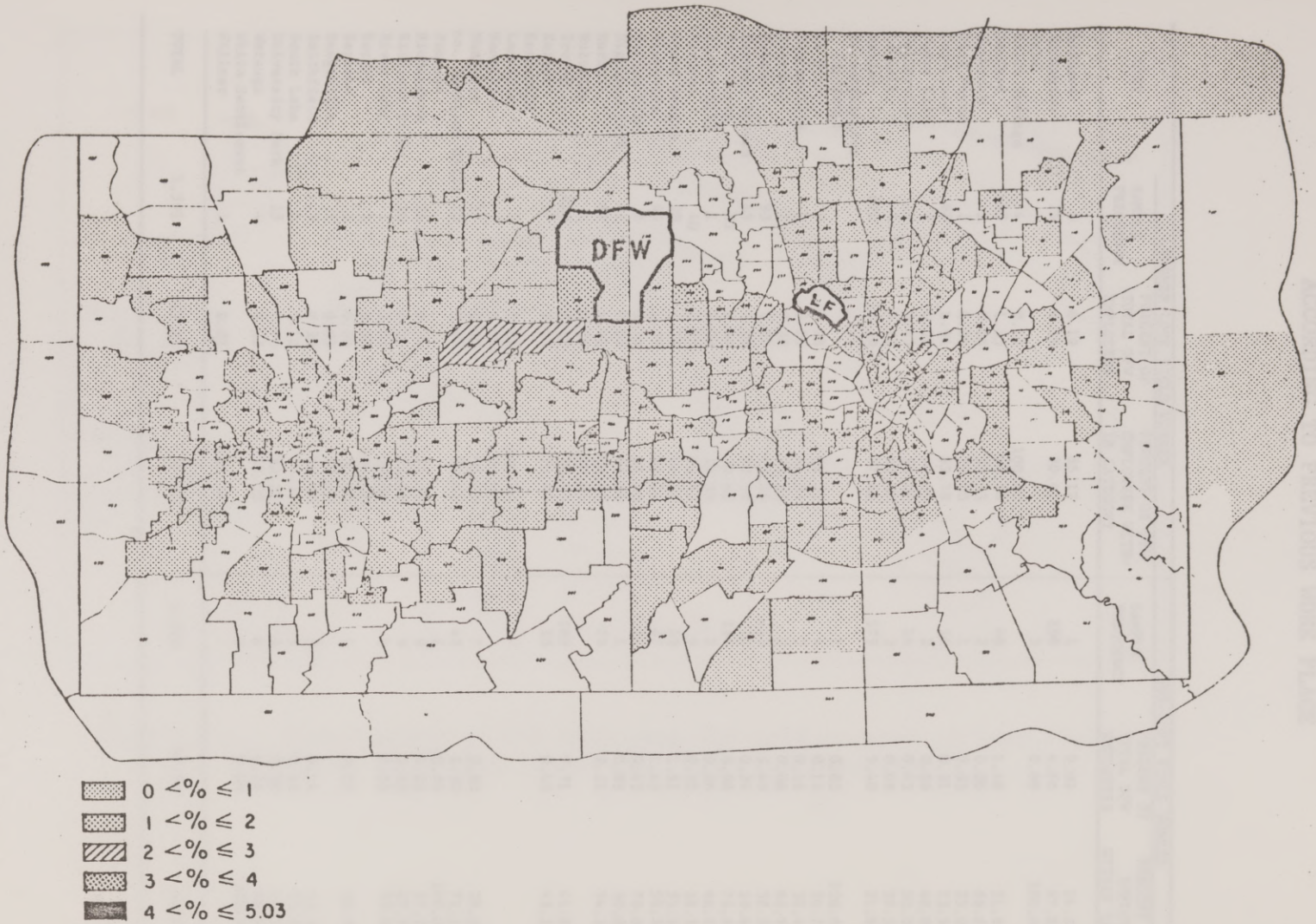


Figure 4.8. Zonal Distribution of DFW Employees Who Did Not Work at Love Field Airport.

TABLE 4.7A. DISTRIBUTION OF DFW EMPLOYEE RESIDENTIAL LOCATION BY CITIES INSIDE THE INTENSIVE STUDY AREA ACCORDING TO PREVIOUS WORK PLACE

CITY	FORMER LOVE FIELD WORKER			NON-LOVE FIELD WORKER		
	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Addison	6	0.19	85.17	1	0.03	14.29
Arlington	71	2.19	30.47	158	4.86	67.81
Azle				3	0.09	100.00
Balch Springs	4	0.12	100.00			
Bedford	43	1.33	46.24	48	1.48	51.61
Benbrook	1	0.03	33.33	2	0.06	66.67
Blue Mound	3	0.09	75.00	1	0.03	25.00
Carrolton	62	1.91	83.78	10	0.31	13.51
Cedar Hill	2	0.06	40.00	2	0.06	40.00
Colleyville	14	0.43	50.00	14	0.43	50.00
Coppell	4	0.12	50.00	3	0.09	37.50
Dallas	622	19.19	77.65	175	5.40	21.84
Dalworthington (Gardens)				1	0.03	100.00
De Soto	9	0.28	69.23	4	0.12	30.77
Duncanville	8	0.25	61.54	5	0.16	38.46
Everman	1	0.03	33.33	2	0.06	66.67
Euless	93	2.87	43.26	113	3.49	52.56
Farmers Branch	45	1.39	80.36	11	0.34	19.64
Fort Worth	53	1.64	20.62	197	6.08	76.65
Forest Hill	1	0.03	33.33	2	0.06	66.67
Garland	40	1.23	81.63	9	0.28	18.37
Grand Praire	30	1.20	44.32	49	1.51	55.68
Grapevine	45	1.39	48.39	47	1.45	50.54
Haltom City	5	0.16	25.00	14	0.43	70.00
Highland Park	1	0.03	50.00	1	0.03	50.00
Hurst	62	1.91	44.93	75	2.31	54.35
Hutchins	1	0.03	100.00			
Irving	230	7.10	56.93	169	5.21	41.83
Keller	17	0.52	56.67	13	0.40	43.33
Kennedale						
Lancaster	4	0.12	100.00			
Mansfiled	3	0.09	100.00			
Mesquite	17	0.52	68.00	7	0.28	28.00
no. Richland Hills	15	0.46	25.42	42	1.30	71.19
Pantego				1	0.03	100.00
Richardson	24	0.74	72.72	9	0.28	27.27
Richland Hills	10	0.31	52.63	9	0.03	47.37
River Oaks	1	0.03	50.00	1	0.03	50.00
Sachse	1	0.03	100.00			
Saginaw	1	0.03	50.00	1	0.03	50.00
Seagoville	1	0.03	50.00			
Smithfield	9	0.28	60.00	5	0.16	33.33
South Lake	4	0.12	44.44	5	0.16	55.55
University Park	15	0.46	83.33	2	0.06	11.11
Watauga	4	0.12	33.33	8	0.25	66.67
White Settlement				3	0.09	100.00
Willmer	1	0.03	100.00			
TOTAL	1,592	49.09	55.70	1,222	37.70	42.76

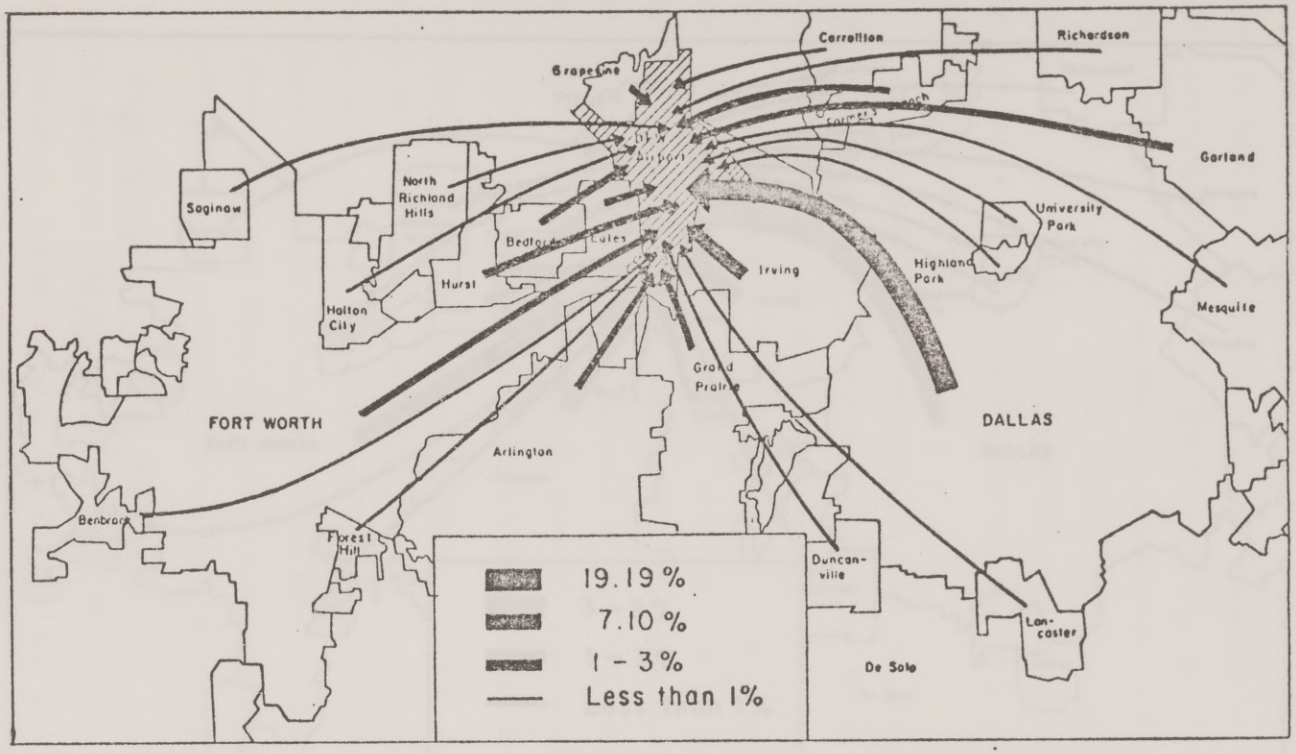


Figure 4.9. Distribution of DFW Employees who used to work at Love Field Airport by Cities Inside the Intensive Study Area.

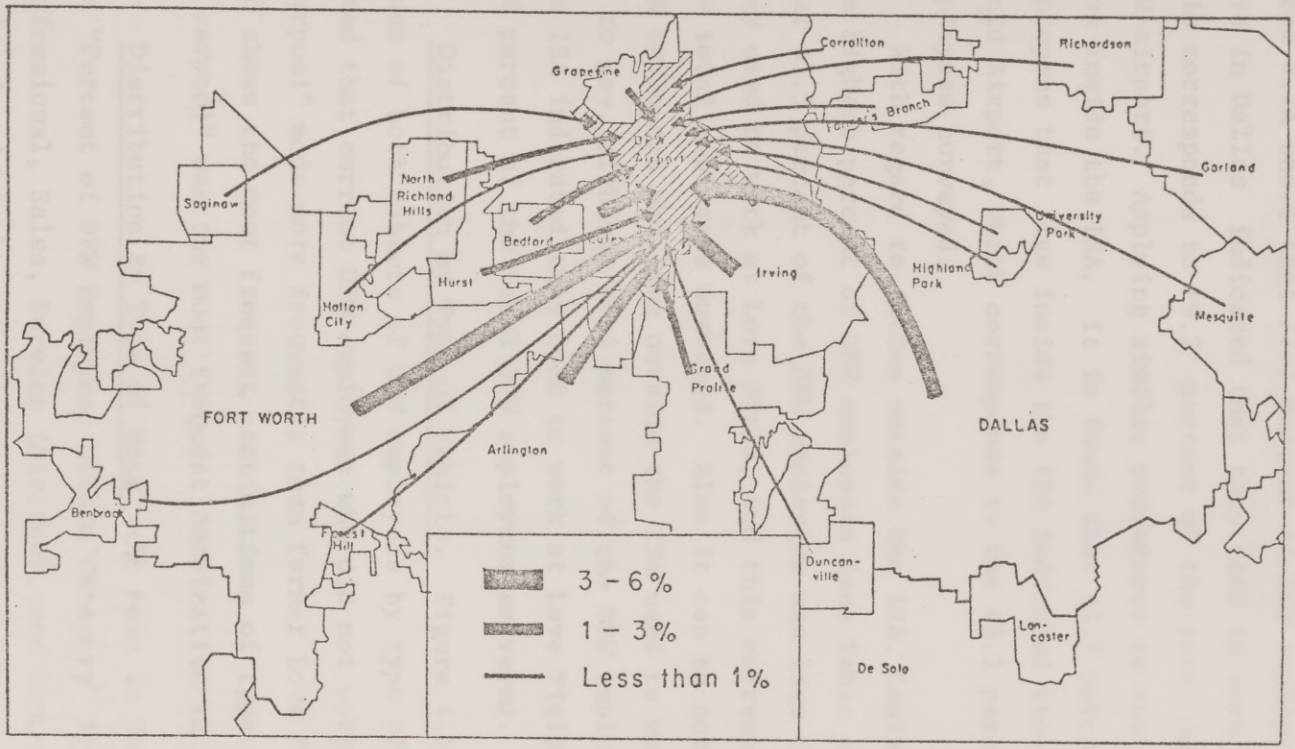


Figure 4.10. Distribution of DFW Employees Who Did not Work At Love Field Airport by Cities Inside the Intensive Study Area-

percentage of DFW employees, exhibit a higher percentage of DFW employees who did not work at Love Field than DFW employees who did.

As can be seen in Table 4.1A, the City of Dallas has the highest sample frequency of DFW employees inside the ISA (801 DFW employees). Table 4.7A shows that 77.7 percent of DFW employees (622 employees) who live in Dallas indicated that they used to work at Love Field Airport. This corresponds to 19.2 percent of the total employees surveyed at DFW airport. Applying similar procedures to the total DFW employees who live inside the ISA, it is found that 55.7 percent of the total DFW employees that live inside the ISA indicated they used to work at Love Field Airport, which corresponds to the 49.1 percent of the total DFW employees surveyed.

With regard to cities outside the ISA, Lewisville is the city with the highest percent of DFW employees (see Table 4.1B). Table 4.7B shows that 65.5 percent of the DFW employees who live in Lewisville indicated they used to work at Love Field, and this corresponds to 2.3 percent of the total employees surveyed. Also it can be noted that most of the DFW employees who live outside the ISA used to work at Love Field. That is to say, although 68.4 percent of the DFW employees who live outside the ISA indicated they used to work at Love Field, this represents only 6.8 percent of the total DFW employees surveyed.

Distribution by Type of Vehicle. Figure 4.11 shows the distributions of both subsets of DFW employees by type of vehicle. It should be noted that current DFW employees who did not work at Love Field use the "carpool" mode more frequently than former Love Field employees. Table 4.8 shows the most frequent combinations of type of vehicle. "Own car or carpool" was the most frequent combination in both cases.

Distribution By Type of Work. As seen in Table 4.9 which compares the "Percent of DFW Employees Within Category" for both subsets, Professional, Sales, Service (Airline), and Rent-a-Car, are the categories in which the percentages of DFW employees who used to work at Love Field are significantly higher than the percentages of DFW employees that did not work at Love Field Airport. On the other hand Service (food), Service (custodian) and Hotel Employee are the categories in which DFW

TABLE 4.7B. DISTRIBUTION OF DFW EMPLOYEE RESIDENTIAL LOCATION BY CITIES OUTSIDE THE INTENSIVE STUDY AREA ACCORDING TO PREVIOUS WORK PLACE

CITY	FORMER LOVE FIELD WORKER			NON-LOVE FIELD WORKER		
	SAMPLE FREQUENCY	% OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	% OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Allen	2	0.06	100.00			
Alvord	1	0.03	100.00			
Argyle	6	0.19	85.71	6	0.03	14.29
Aubrey	1	0.03	100.00			
Blue Ridge	2	0.06	100.00			
Bonham	1	0.03	100.00			
Bowie	1	0.03	100.00			
Boyd	3	0.09	50.00	3	0.09	50.00
Bridgeport	2	0.06	50.00	2	0.06	50.00
Celina	2	0.06	100.00			
Celeste	1	0.03	100.00			
Cleburne				1	0.03	100.00
Clifton	1	0.03	100.00			
Collinsville	1	0.03	100.00			
Conroe				1	0.03	100.00
Decatur	1	0.03	100.00			
Denton	24	0.74	77.42	7	0.22	22.58
Elmo	2	0.06	100.00			
Ennis	2	0.06	100.00			
Fairfield	1	0.03	100.00			
Farmersville	1	0.03	100.00			
Ferris	1	0.03	50.00	1	0.03	50.00
Flower Mound	1	0.03	50.00	1	0.03	50.00
Frisco	5	0.16	62.50	3	0.09	37.50
Gainsville				1	0.03	100.00
Granbury	1	0.03	100.00			
Gordon	1	0.03	100.00			
Greenville				1	0.03	100.00
Joshua	1	0.03	50.00	1	0.03	50.00
Justin	1	0.03	25.00	3	0.09	75.00
Highland Village	1	0.03	100.00			
Kerns				1	0.03	100.00
Lake Dallas	4	0.12	66.67	1	0.03	16.67
Little Elm	1	0.03	100.00			
Lewisville	74	0.28	65.49	36	1.11	31.85
Mabank	2	0.06	66.67	1	0.03	33.33
McKinney	7	0.22	77.77	2	0.06	22.22
Midlothian	1	0.03	100.00			
Nevada	1	0.03	100.00			
Nocona						
Paradise				1	0.03	100.00
Plano	18	0.55	69.23	8	0.25	30.77
Pilot Point	2	0.06	100.00			
Ponder	1	0.03	50.00	1	0.03	50.00
Poolville	1	0.03	100.00			
Quinlan	1	0.03	100.00			
Red Oak	2	0.06	100.00			
Rhome				1	0.03	100.00
Roanoke	20	0.61	66.67	10	0.31	33.33
Rockwall	1	0.03	33.33			
San Marcos	1	0.03	100.00			
Sange	2	0.06	66.67	1	0.03	33.33
Sunset				1	0.03	100.00
Tioga	1	0.03	100.00			
Valleyview	2	0.06	100.00			
Weatherford	1	0.03	33.33	2	0.06	66.67
Waxahachie	4	0.12	80.00	1	0.03	20.00
Wills Point	1	0.03	100.00			
Whitewright				1	0.03	100.00
Wylie	4	0.12	100.00			
TOTAL	219	6.76	68.44	94	2.90	20.39

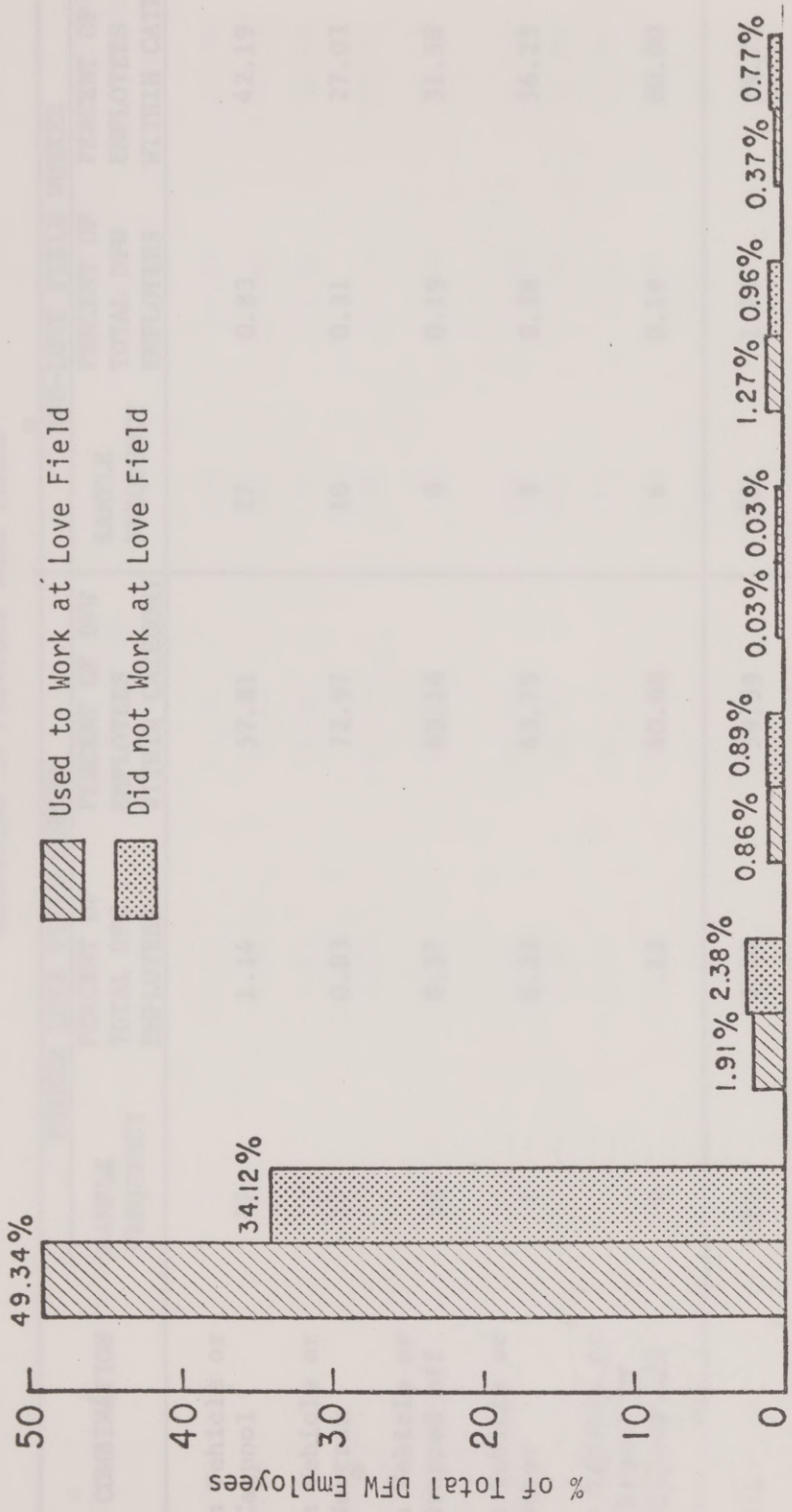


Figure 4.11. DFW Employees Work Travel Mode According to Previous Work Place.

TABLE 4.8. MODE COMBINATIONS USED BY DFW EMPLOYEES IN THEIR WORK TRIPS ACCORDING TO PREVIOUS WORK PLACE

COMBINATION	FORMER LOVE FIELD WORKER			NON-LOVE FIELD WORKER		
	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Own Vehicle or Carpool	37	1.14	57.81	27	0.83	42.19
Own Vehicle or Surtran	27	0.83	72.97	10	0.31	27.03
Own Vehicle or Dropped off	12	0.37	63.16	6	0.19	31.58
Own Vehicle or Other	7	0.22	43.75	9	0.28	56.25
Own Vehicle or Carpool or Dropped off	4	.12	40.00	6	0.19	60.00
TOTAL	87	2.68	59.59	58	1.79	39.73

TABLE 4.9. DISTRIBUTION OF DFW EMPLOYEES BY OCCUPATION ACCORDING TO PREVIOUS WORK PLACE

OCCUPATION	FORMER LOVE FIELD WORKER			NON-LOVE FIELD WORKER		
	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Professional	647	19.96	65.35	332	10.24	33.50
Clerical	203	6.26	52.19	181	5.58	46.53
Sales	127	3.92	70.56	52	1.60	38.89
Craftsman Foreman	43	1.33	59.72	24	0.74	33.33
Technician Operator	44	1.36	38.94	67	2.06	59.29
Maintenance	107	3.30	45.92	120	3.70	51.50
Other Labor	151	4.66	40.37	219	6.75	58.56
Service(Food)	68	2.10	36.17	114	3.51	60.64
Service(Airline)	384	11.85	78.21	106	3.27	21.59
Service(Custodian)	8	0.25	21.62	29	0.89	78.38
Rent-a-Car	18	0.56	62.07	11	0.33	37.93
Hotel Employee	0	0	0	29	0.89	90.62
No Response	50	1.54	44.25	54	1.67	47.79
TOTAL	1,850	57.08	57.08	1,338	41.28	41.28

employees that did not work at Love Field exhibit significantly higher percentages than former Love Field employees.

It can be noted that those in the "professional" category who indicated that they formerly worked at Love Field constitute the higher "Percent of Total DFW Employees" (19.96%).

Distribution by Level of Income. Figure 4.12 shows each DFW employee subset by level of income. As expectly, most of the DFW employees with high income levels previously worked at Love Field Airport. Also, it should be noted that the former Love Field employees have a significantly higher percent in the $13,000 - $20,000 income level range than the DFW employees who did not work at Love Field. On the other hand, DFW employees who did not work at Love Field present a significantly higher percent of the "under $6,000" income level range than DFW employees who did.

Distribution by Age and Sex. Table 4.10 shows the distribution of the subsets of DFW employees by age. Comparing the two subsets with regard to percent of DFW Employees Within Category", it can be seen that the category "Under 21" persents a higher percent of DFW employees in the "Non-Love Field Worker" subset than in the "Former Love Field Workers" category. In the remaining categories, the subset "Former Love Field Worker" shows higher percent than "Non-Love Field Worker."

Table 4.11 shows the distribution by sex for both subsets. It can be noted that the difference of percent between males for both subsets is significantly greater than the difference of percent between females. This can be understood as an increase of job opportunities for women.

As can be seen in all the above tables, most of the percentages of DFW employees within each category do not sum to one hundred percent. The explanation for this is that the question concerning whether or not the employee previously worked at Love Field was not answered by all employees.

In conclusion, the analysis of data presented in this chapter allows the study of such topics as:

1. The impact of Dallas-Fort Worth Regional Airport in the distributions of DFW employee residential location.

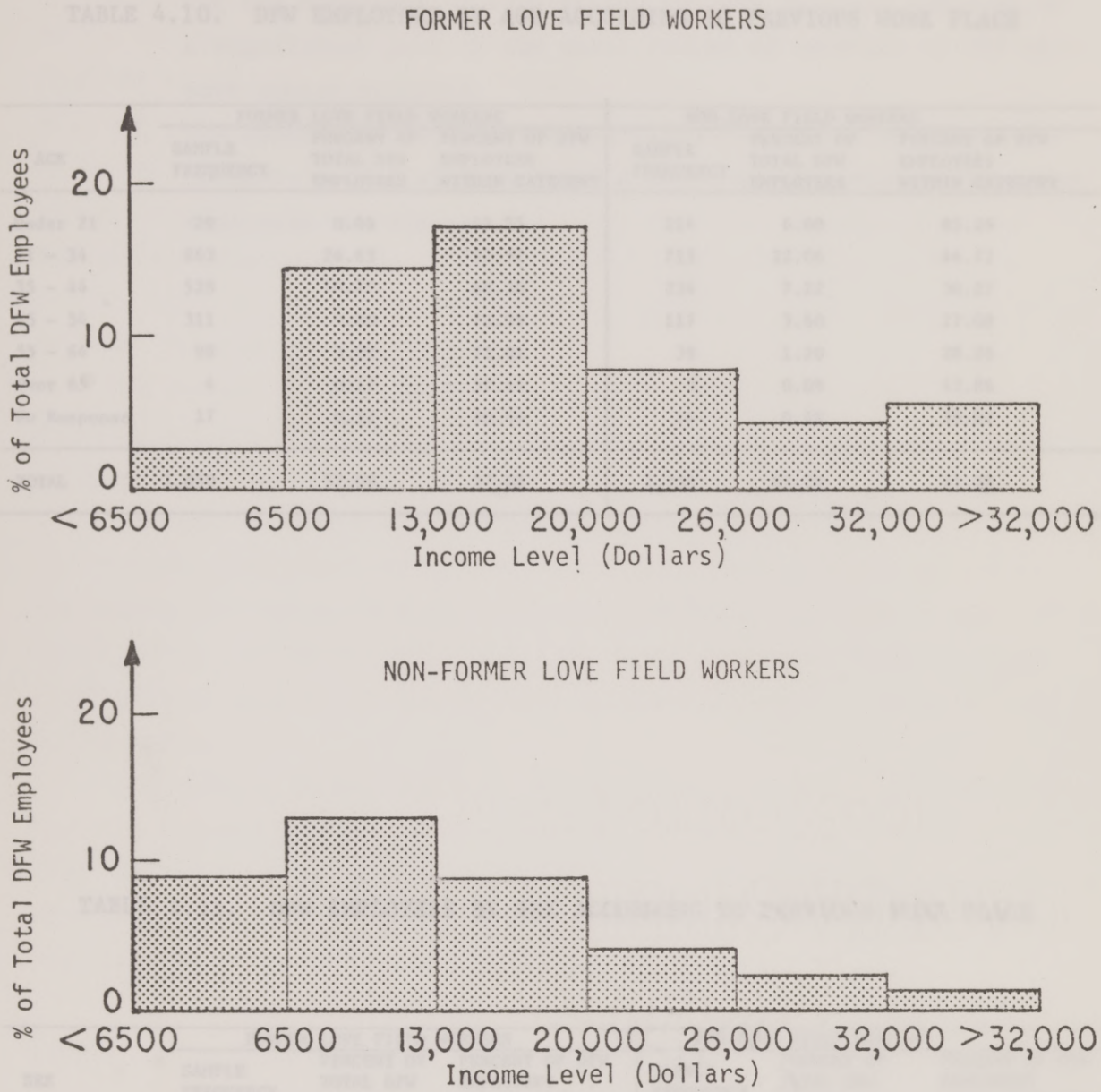


Figure 4.12. DFW Employees by Income Level According to Previous Work Place.

TABLE 4.10. DFW EMPLOYEES BY AGE ACCORDING TO PREVIOUS WORK PLACE

AGE	FORMER LOVE FIELD WORKERS			NON-LOVE FIELD WORKERS		
	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Under 21	29	0.89	11.55	214	6.60	85.26
21 - 34	863	26.63	53.97	715	22.06	44.72
35 - 44	528	16.29	68.30	234	7.22	30.27
45 - 54	311	9.60	71.99	117	3.60	27.08
55 - 64	98	3.02	71.01	39	1.20	28.26
Over 65	4	0.12	57.14	3	0.09	42.86
No Response	17	0.52	40.46	16	0.49	39.02
TOTAL	1,850	57.08	57.08	1,338	41.28	41.28

TABLE 4.11. DFW EMPLOYEES BY SEX ACCORDING TO PREVIOUS WORK PLACE

SEX	FORMER LOVE FIELD WORKERS			NON-LOVE FIELD WORKERS		
	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY	SAMPLE FREQUENCY	PERCENT OF TOTAL DFW EMPLOYEES	PERCENT OF DFW EMPLOYEES WITHIN CATEGORY
Male	1,237	38.17	60.28	790	24.38	38.50
Female	570	17.59	51.58	518	15.98	46.88
No Response	43	1.33	51.19	30	0.92	35.71
TOTAL	1,850	57.08	57.08	1,338	41.28	41.28

2. The distribution of DFW employees by type of vehicle, reflecting the necessity of considering the DFW employee vehicles as a significant part of the total volume of vehicles at the airport access highways.
3. The common and different characteristics of DFW employees who formerly worked at Love Field Airport in comparison with those employees who did not.

CHAPTER V. ARRIVAL AND DEPARTURE DISTRIBUTIONS OF DFW EMPLOYEES

The DFW Airport, taken as a whole, is one of the largest employers in the Dallas/Fort Worth area and as such is a major traffic generator from the standpoint of employee vehicles alone. In addition, the arrivals and departures of employees adds to the traffic volumes generated by normal airline activity. This must be considered both in modeling airport access volumes and in the subsequent design of airport access facilities. Therefore the distribution of employees' arrival and departure times at the airport relative to their work shift times is of critical interest in this research.

The purpose of this chapter is to describe the conceptual basis for modeling the distribution of DFW employees' arrival and departure times at the airport relative to the work shift starting and ending times.

The term "time difference" will be applied to the difference between the starting work shift time and the time that DFW employees arrive, or the difference between the time that DFW employees leave the airport and their ending work shift time. The term "time-difference data distribution" will be applied to the statistical distribution of the above time differences.

This chapter is divided into two sections. The first section deals with the selection of the periods of day for which the time-difference data distributions are going to be specified. The second section deals with goodness-of-fit tests of selected theoretical distributions against the observed time difference data distributions.

Determination of the Periods of Day for Analysis

Figures 5.1 and 5.2 show histograms of the percentages of DFW employees versus starting work shift times and ending work shift times, respectively, during a normal work day. In the case of percent of DFW employees versus starting work shift time, it can be noted from Fig. 5.1 that there are five distinguishable periods whose limits were tentatively selected as: 0 through 4 for the first period, 4 through 10 for the second period, 10 through 13 for the third period, 13 through 20 for the

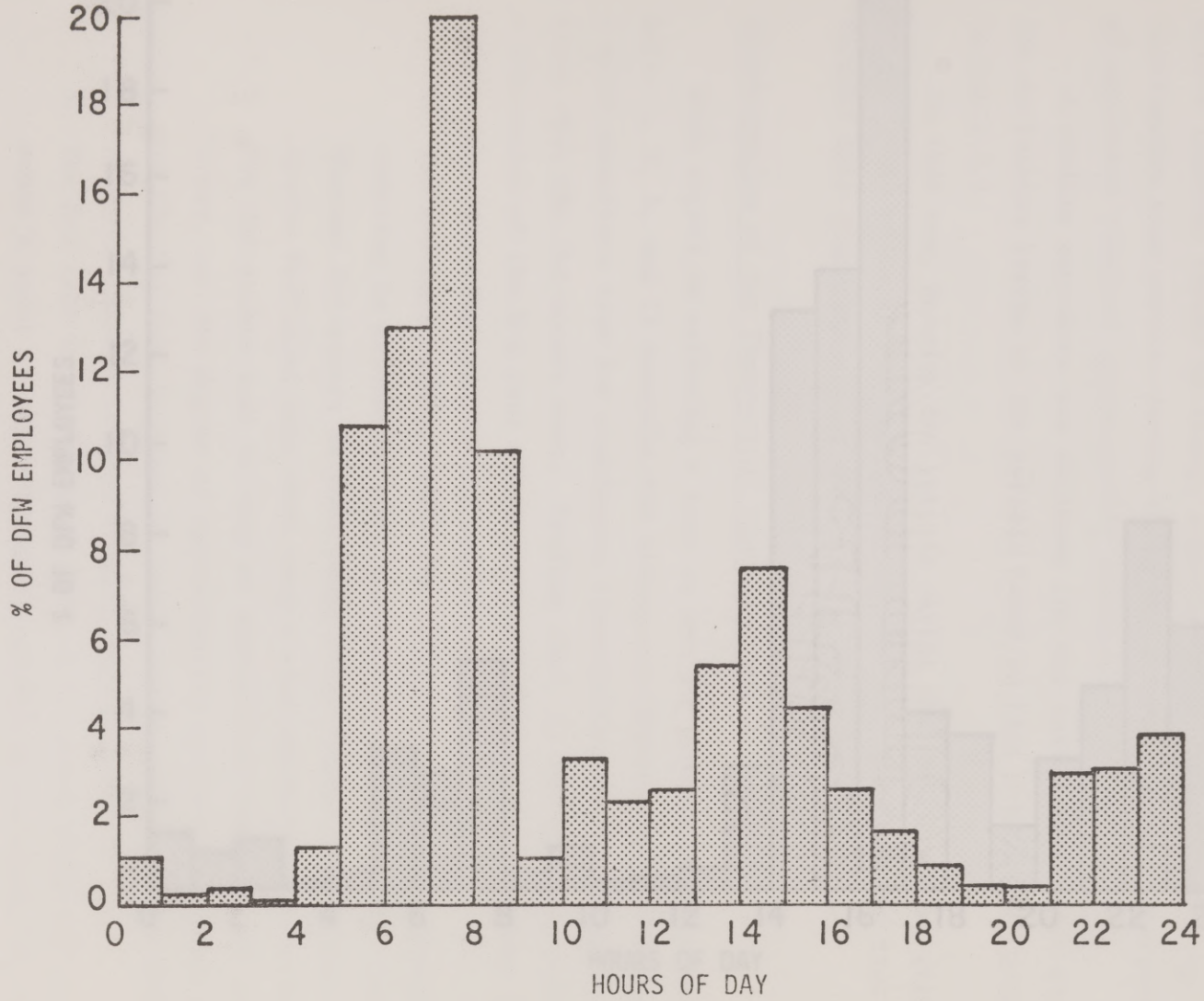


Figure 5.1. Distribution of Work Shift Starting Times of DFW Employees

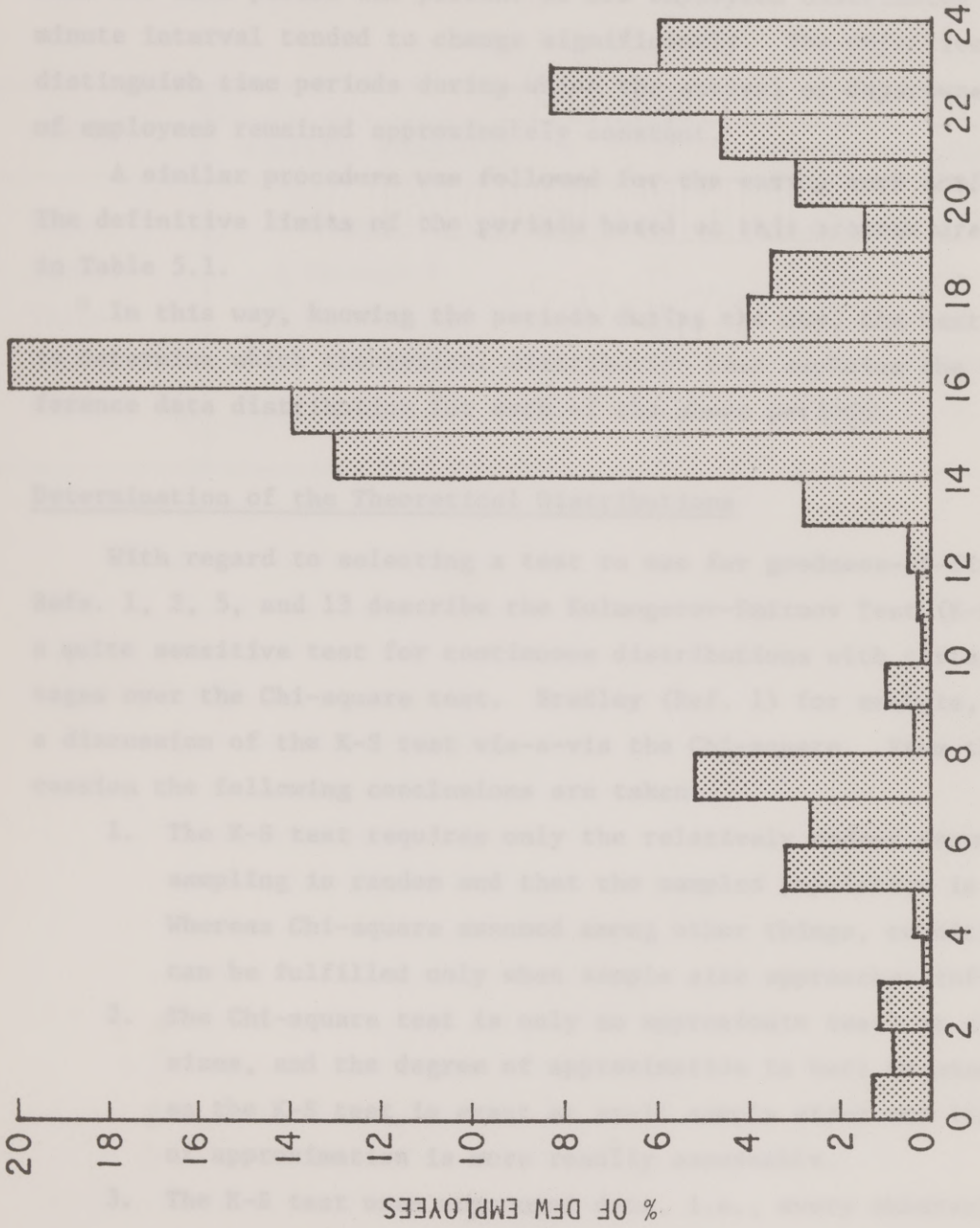


Figure 5.2. Distribution of Work Shift Ending Times of DFW Employees.

fourth period, and 20 through 24 for the fifth period. With the help of "Statistical Package for the Social Sciences" (Ref. 10) a range of alternative limits around the above tentative ones were tested, and fixed when for each period the percent of DFW employees distributed by five-minute interval tended to change significantly. The objective was to distinguish time periods during which the arrival or departure patterns of employees remained approximately constant.

A similar procedure was followed for the ending work shift periods. The definitive limits of the periods based on this process are presented in Table 5.1.

In this way, knowing the periods during the day, the next step was to determine which theoretical distribution best explains the time difference data distribution for each of the above periods.

Determination of the Theoretical Distributions

With regard to selecting a test to use for goodness-of-fit analysis, Refs. 1, 2, 5, and 13 describe the Kolmogorov-Smirnov Test (K-S Test) as a quite sensitive test for continuous distributions with certain advantages over the Chi-square test. Bradley (Ref. 1) for example, presents a discussion of the K-S test vis-a-vis the Chi-square. From that discussion the following conclusions are taken:

1. The K-S test requires only the relatively modest assumption that sampling is random and that the sampled population is continuous. Whereas Chi-square assumed among other things, conditions that can be fulfilled only when sample size approaches infinity.
2. The Chi-square test is only an approximate test, at all sample sizes, and the degree of approximation is hard to assess, whereas the K-S test is exact at small sample sizes and its degree of approximation is more readily assessable.
3. The K-S test uses ungrouped data, i.e., every observation represents a point at which "goodness-of-fit is examined; Chi-square loses this information (if the hypothesized distribution is continuous) by requiring that data be grouped into cells.

Therefore, the K-S test was chosen as the test to be applied in this study.

TABLE 5.1. LIMITS OF PERIODS OF STARTING AND ENDING WORK SHIFTS

PERIOD	TIME	
	STARTING WORKSHIFT	ENDING WORKSHIFT
First	0 through 5	0 through 6
Second	5 through 9	6 through 10
Third	9 through 13	10 through 14
Fourth	13 through 21	14 through 19
Fifth	21 through 24	19 through 24

The K-S test is based on the simple measurement of the maximum vertical difference between two cumulative distribution functions; in this case, the cumulative probability time difference data distribution and selected theoretical cumulative probability distributions. This difference, once determined, is then compared with the values of K-S statistics for the appropriate sample size, and level of significance. A significance level of 0.05 is assumed in this study.

Figure 5.3 shows an example of a typical distribution of the time difference data. From a simple visual inspection of the time difference data distribution for each period, the following observations are made:

1. The theoretical distributions most likely to fit the time difference distributions are:
   a) Normal distribution
   b) Lognormal distribution
   c) Exponential distribution (negative)
   d) Gamma distribution
   e) Erlang distribution
2. When DFW employees were asked what time they arrived at or left the airport there was a tendency to express their answer to the nearest five minutes. Therefore, the intervals selected, were five minutes in length centered around even five-minute epochs, i.e., the actual boundaries were defined according to the formula 5 (N + 0.5), where N is a positive integer (the first interval has the integer lower bound of 0.0). These interval boundaries also ensure that individual integer responses fall within an interval and not on a border between two intervals.

Figure 5.4 is a flow chart which was developed to show the sequence of the steps followed in finding the theoretical distribution that best fits the time difference data distribution. First of all, the data were divided randomly into two parts. This division was made because of the K-S test requirement that the parameters of the theoretical distribution should not be obtained from the same sample that is tested (Ref. 5). From one subset of the data the sample mean and variance are computed and used to estimate the parameters of each theoretical distribution.

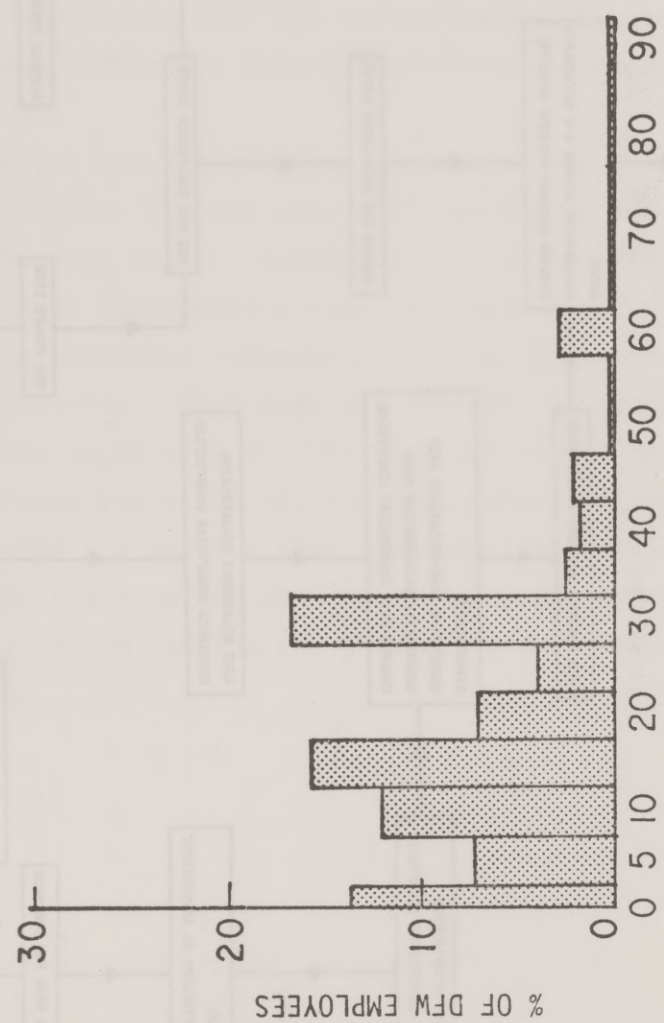


FIGURE 5.3. Typical Distribution Of Time-Difference Data.

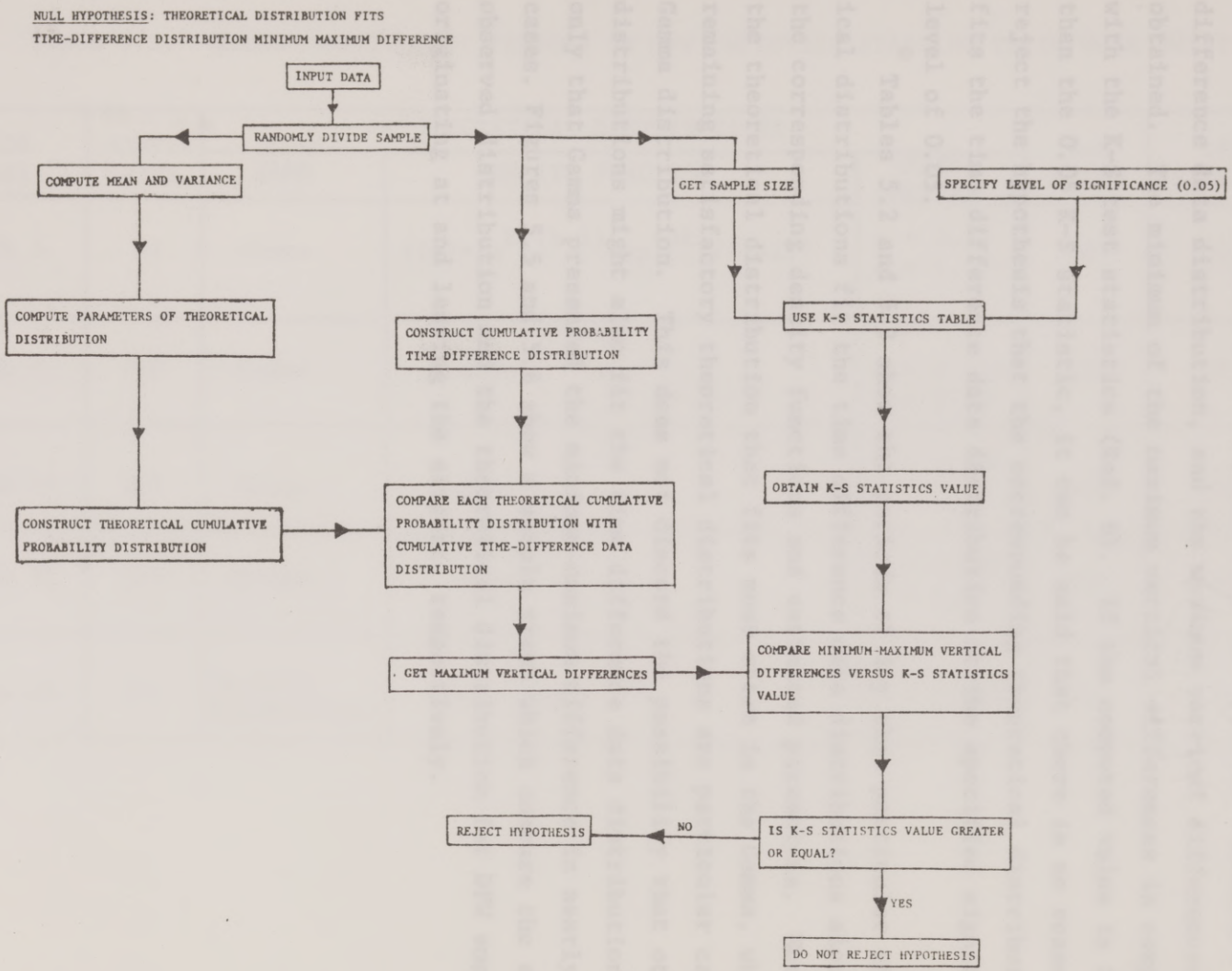


Figure 5.4. Procedure for Fitting Time Difference Distribution

From the other part of the sample the observed cumulative probability time difference data distribution is constructed. Then, each cumulative theoretical distribution is compared with the observed cumulative time difference data distribution, and the maximum vertical differences are obtained. The minimum of the maximum vertical differences is compared with the K-S test statistics (Ref. 6). If the computed value is less than the 0.05 K-S statistic, it can be said that there is no reason to reject the hypothesis that the corresponding theoretical distribution fits the time difference data distribution at the specified significance level of 0.05.

Tables 5.2 and 5.3 show the periods of day that particular theoretical distributions fit the time difference data distributions along with the corresponding density functions and estimated parameters. Note that the theoretical distribution that fits most often is the Gamma, while the remaining satisfactory theoretical distributions are particular cases of Gamma distribution. This does not discard the possibility that other distributions might also fit the time difference data distribution, but only that Gamma presented the minimum-maximum difference in nearly all cases. Figures 5.5 and 5.6 show a sample graph which compare the actual observed distribution and the theoretical distribution for DFW employees originating at and leaving the airport, respectively.

TABLE 5.2. CHARACTERISTICS OF PERIODS OF DFW EMPLOYEES STARTING THEIR WORK SHIFTS.

PERIOD OF DAY (HRS)	SAMPLE SIZE	THEORETICAL DISTRIBUTIONS			K-S VALUE	LEVEL OF SIGNIFICANCE
		NAME	DENSITY FUNCTION	PARA-METERS		
0 through 5	41	Gamma	$f(x)=(\alpha^k x^{(k-1)} \exp^{-\alpha k})/(k-1)!$	$\alpha = 0.52$ $k = 1.15$	.189	0.1
5 through 9	716	Gamma	Same	$\alpha = 0.065$ $k = 1.13$	.049	0.05
9 through 13	166	Gamma	Same	$\alpha = 0.053$ $k = 1.44$	.105	0.05
13 through 21	379	Gamma	Same	$\alpha = 0.067$ $k = 1.67$	.069	0.05
21 through 24	144	Negative Exponential	$f(x) = \alpha \exp^{-\alpha x}$	$\alpha = 0.042$	.105	0.05

TABLE 5.3. CHARACTERISTICS OF PERIODS OF DFW EMPLOYEES ENDING THEIR WORK SHIFTS.

PERIOD OF DAY (HRS.)	SAMPLE SIZE	THEORETICAL DISTRIBUTIONS			K-S VALUES	LEVEL OF SIGNIFICANCE
		NAME	DENSITY FUNCTION	PARA-METERS		
0 through 6	107	Erlang (Round Up)	$f(x)=(\alpha^{k} x^{(k-1)} \exp^{-\alpha k})/(k-1)!$	$\alpha = 0.078$ $k = 2.0$	.131	0.05
6 through 10	131	Gamma	$f(x)=(\alpha^{1} x^{(k-1)} \exp^{-\alpha k})/(k-1)!$	$\alpha = 0.081$ $k = 1.79$	.106	0.10
10 through 14	78	Gamma	Same	$\alpha = 0.056$ $k = 1.46$	.138	0.10
14 through 19	686	Negative Exponential	$f)x) = \alpha \exp^{-\alpha x}$	$\alpha = 0.057$	.052	0.05
19 through 21	341	Gamma	Same	$\alpha = 0.065$ $k = 1.64$	.074	0.05

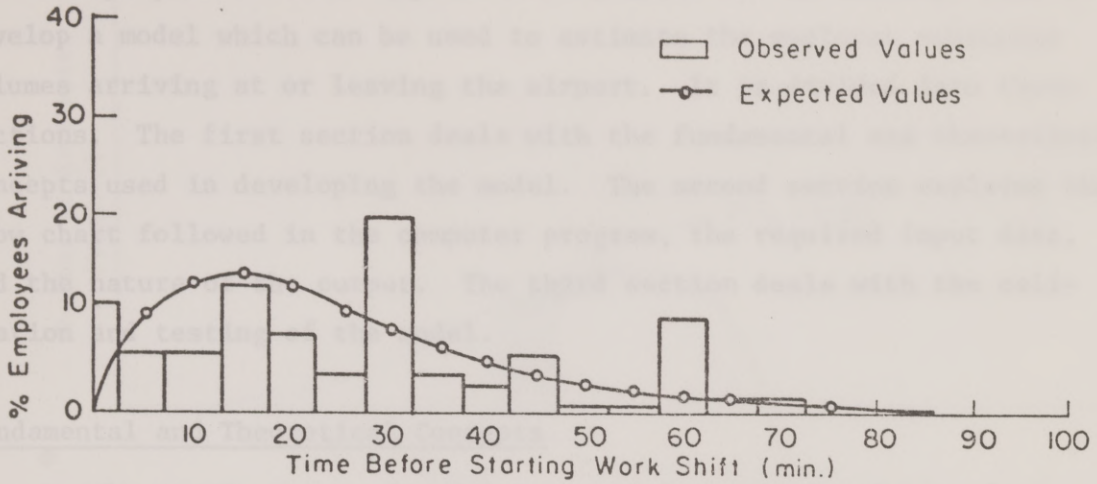


Figure 5.5. Sample Distribution for DFW Employees Arriving at The DFW Airport.

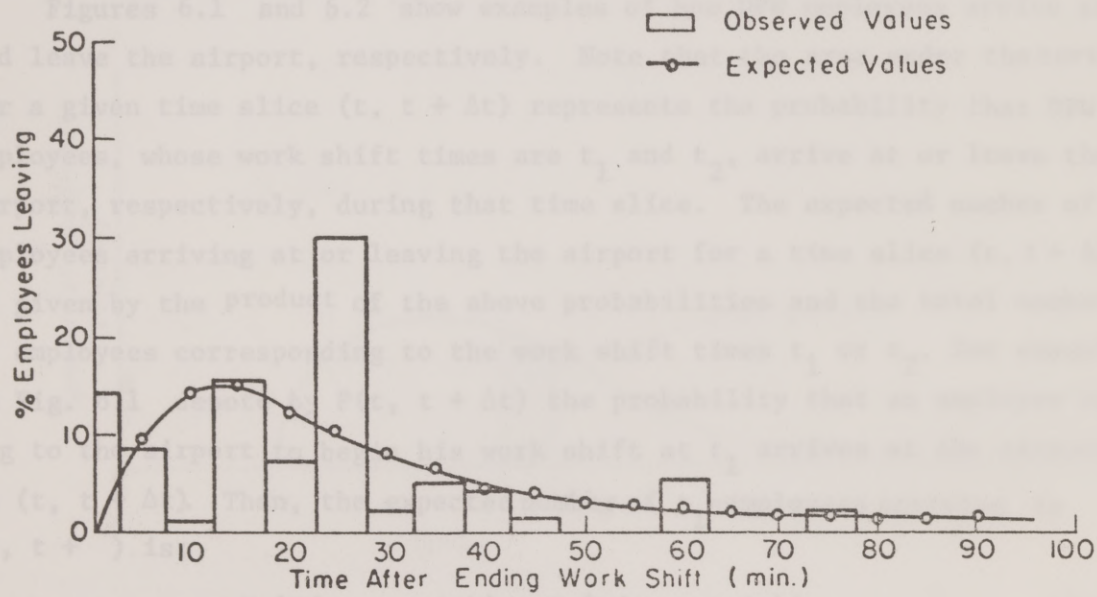


Figure 5.6. Sample Distribution for DFW Employees Leaving the DFW Airport.

CHAPTER VI. MODEL DEVELOPMENT

The purpose of this chapter is to present the methodology used to develop a model which can be used to estimate the employee vehicular volumes arriving at or leaving the airport. It is divided into three sections. The first section deals with the fundamental and theoretical concepts used in developing the model. The second section explains the flow chart followed in the computer program, the required input data, and the nature of the output. The third section deals with the calibration and testing of the model.

Fundamental and Theoretical Concepts

In Chapter V, it was found for particular periods of time during the day, the way by which DFW employees arrive at or leave the airport can be satisfactorily approximated by a distinct theoretical distribution (one distribution for arrival and one distribution for leaving). That is to say, for all the DFW employees whose work shift times in a certain period, the way that they arrive at or leave the airport will be distributed approximately the same.

Figures 6.1 and 6.2 show examples of how DFW employees arrive at and leave the airport, respectively. Note that the area under the curves for a given time slice $(t, t + \Delta t)$ represents the probability that DFW employees, whose work shift times are t_1 and t_2, arrive at or leave the airport, respectively, during that time slice. The expected number of employees arriving at or leaving the airport for a time slice $(t, t + \Delta t)$ is given by the product of the above probabilities and the total number of employees corresponding to the work shift times t_1 or t_2. For example, in Fig. 6.1 denote by $P(t, t + \Delta t)$ the probability that an employee coming to the airport to begin his work shift at t_1 arrives at the airport in $(t, t + \Delta t)$. Then, the expected number of t_1-employees arriving in $(t, t +)$ is:

$$E\{N(t, t + \Delta t)\} = N\{P(t, t + \Delta t)\} \qquad (1)$$

where $E\{N(t, t + \Delta t)\}$ is the expected number of employees with work shift time t_1 arriving in the $(t, t + \Delta t)$ time slice, and N is the total

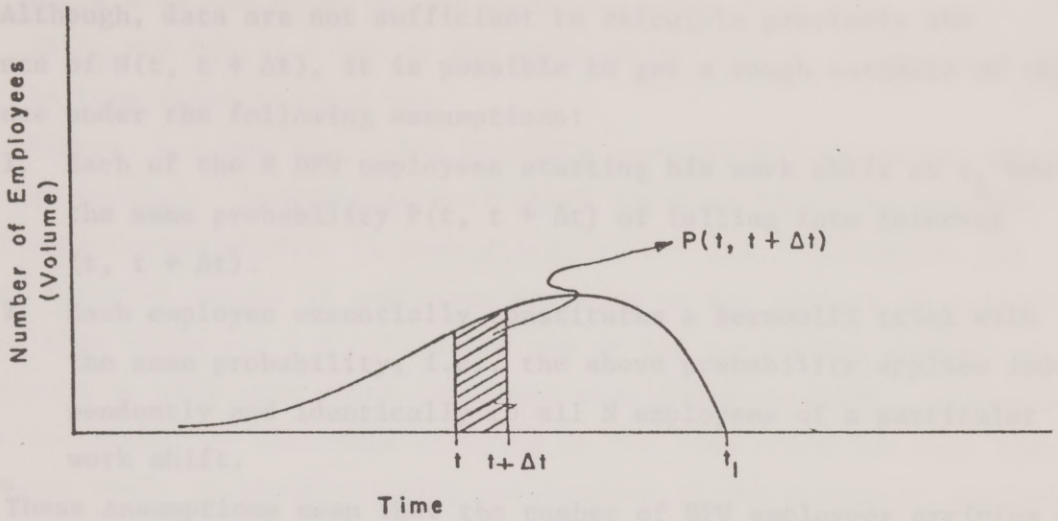


Figure 6.1. Employee Vehicles Arrival Patterns
(Single Work Shift Time).

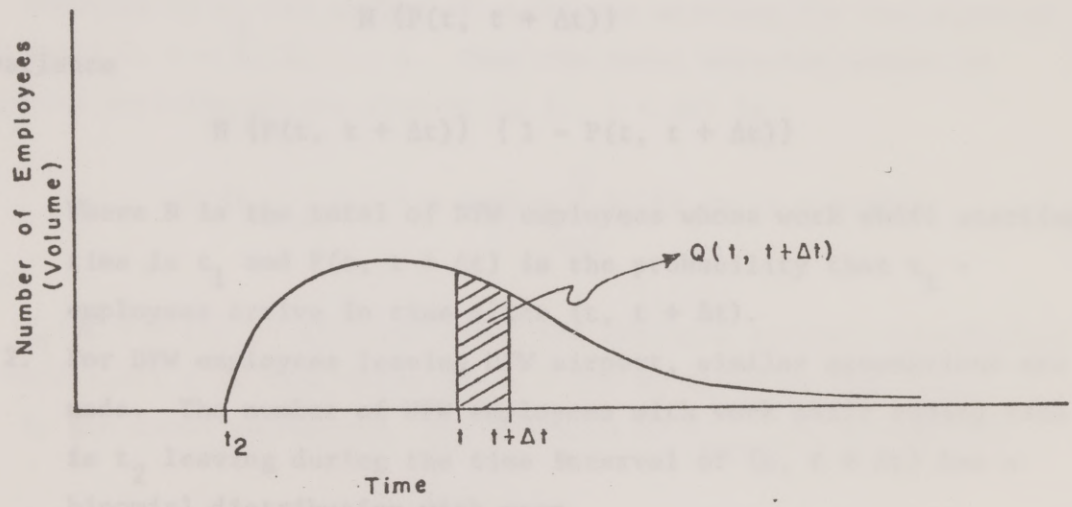


Figure 6.2. Employee Vehicles Departure Patterns
(Single Work Shift Time).

volume (number) of employees with work shift time t_1.

Although, data are not sufficient to calculate precisely the variance of $N(t, t + \Delta t)$, it is possible to get a rough estimate of this variance under the following assumptions:

1. Each of the N DFW employees starting his work shift at t_1 has the same probability $P(t, t + \Delta t)$ of falling into interval $(t, t + \Delta t)$.
2. Each employee essentially constitutes a Bernoulli trial with the same probability, i.e., the above probability applies independently and identically to all N employees of a particular work shift.

These assumptions mean that the number of DFW employees arriving at or leaving (independently of each other) the airport at time slice $(t, t + \Delta t)$ has a binomial distribution with mean $N\{P(t, t + \Delta t)\}$ and variance $N\{P(t, t + \Delta t)\}\{1 - P(t, t + \Delta t)\}$.

So far, the following conclusions can be made:

1. For DFW employees arriving at the DFW airport and whose work shift starting time is t_1, the number of employees arriving at time interval $(t, t + \Delta t)$ has a binomial distribution with mean

$$N\{P(t, t + \Delta t)\}$$

and variance

$$N\{P(t, t + \Delta t)\}\{1 - P(t, t + \Delta t)\}$$

Where N is the total of DFW employees whose work shift starting time is t_1 and $P(t, t + \Delta t)$ is the probability that t_1 - employees arrive in time slice $(t, t + \Delta t)$.

2. For DFW employees leaving DFW airport, similar assumptions are made. The number of DFW employees with work shift ending time is t_2 leaving during the time interval of $(t, t + \Delta t)$ has a binomial distribution with mean

$$M\{Q(t, t + \Delta t)\}$$

and variance

$$M\{Q(t, t + \Delta t)\}\{1 - Q(t, t + \Delta t)\}$$

where M is the total of DFW employees whose work shift ending time is t_2 and $Q(t, t + \Delta t)$ is the probability that t_2 - employees leave in time slice $(t, t + \Delta t)$.

Figure 6.3 and 6.4 show multiple work shift time curves (starting and ending). Considering work shift starting time, for example, note that many curves overlap in time slice $(t, t + \Delta t)$. Therefore, the total expected volume of employees arriving at the airport in a particular time slice $(t, t + \Delta t)$ is the sum of the individual volumes of employees in that time slice from each starting work shift. Assuming that the number of employees arriving in the time slice for each starting work shift is stochastically independent of the number of employees in that time slice for any other starting work shift, it can also be concluded that the variance of total volume of employees with different work shift starting time arriving in time slice $(t, t + \Delta t)$ is the sum of each individual variance for that time slice since the variance of the sum of independent random variables is simply the sum of the individual variances. Similar considerations and conclusions apply to work shift ending times, and volumes of employees leaving the airport at the ends of work shifts.

Denoting by N_i the number of employees arriving for the start of work shift i, i = 1, 2, ... n. Then the total expected number of employees arriving at the airport in $(t, t + \Delta t)$ is

$$E\{N_{total}(t, t + \Delta t)\} = \sum_{i=1}^{n} N_i \{P_i(t, t + \Delta t)\} \qquad (2)$$

where

$P_i(t, t + \Delta t)$ is the area under the employee arrival distribution for work shift i in time slice $(t, t + \Delta t)$ as shown in Fig. 6.3.

By the above assumption, the variance of $N_{total}(t, t + \Delta t)$ is

$$\text{Var}\{N_{total}(t, t + \Delta t)\} = \sum_{i=1}^{n} N_i \{P_i(t, t + \Delta t)\} \{1 - P_i(t, t + \Delta t)\} \qquad (3)$$

Similarly, the mean and variance of the total number of employees leaving the airport in a particular time slice from various ending work shifts are

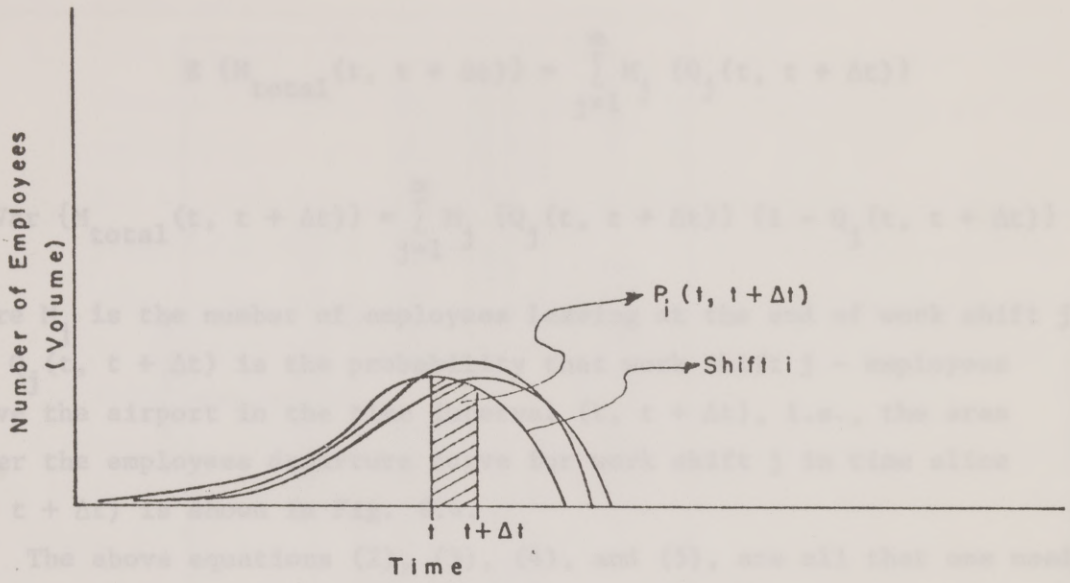


Figure 6.3. Employee Vehicles Arrival Patterns
(Overlapping of Curves)

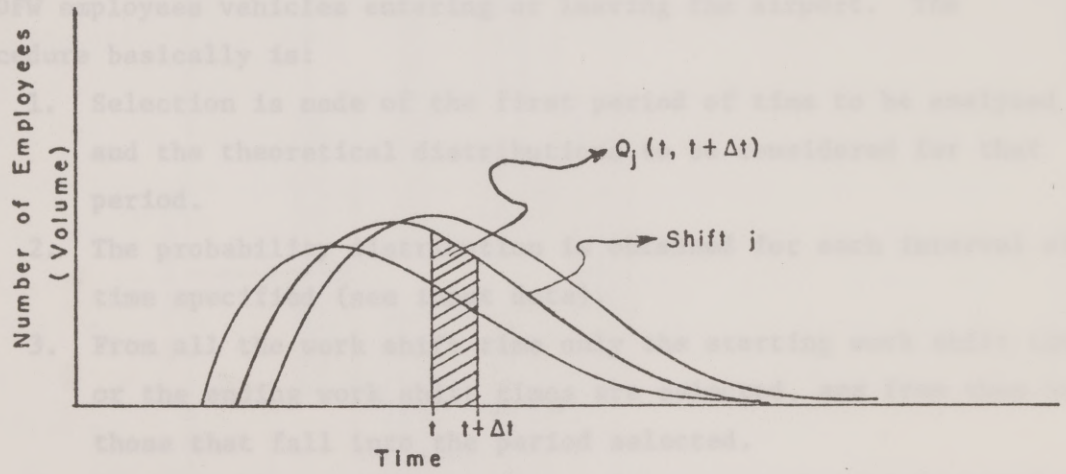


Figure 6.4. Employee Vehicles Departure Patterns
(Overlapping of Curves).

$$E\{M_{total}(t, t + \Delta t)\} = \sum_{j=1}^{m} M_j \{Q_j(t, t + \Delta t)\} \quad (4)$$

and

$$Var\{M_{total}(t, t + \Delta t)\} = \sum_{j=1}^{m} M_j \{Q_j(t, t + \Delta t)\}\{1 - Q_j(t, t + \Delta t)\} \quad (5)$$

Where M_j is the number of employees leaving at the end of work shift j and $Q_j(t, t + \Delta t)$ is the probability that work shift j - employees leave the airport in the time interval $(t, t + \Delta t)$, i.e., the area under the employees departure curve for work shift j in time slice $(t, t + \Delta t)$ is shown in Fig. 6.4.

The above equations (2), (3), (4), and (5), are all that one needs to compute the mean and variance of the total number of employees arriving at and leaving the airport in any arbitrary time slice $(t, t + \Delta t)$. Procedures for the actual computation of employee volumes are described below.

Computation of Employees Vehicular Volumes

Figure 6.5 shows the flow chart followed to determine the volumes of DFW employees vehicles entering or leaving the airport. The procedure basically is:

1. Selection is made of the first period of time to be analyzed and the theoretical distributions to be considered for that period.
2. The probability distribution is obtained for each interval of time specified (see input data).
3. From all the work shift time only the starting work shift times or the ending work shift times are selected, and from them only those that fall into the period selected.
4. The vehicular volume and the variance at each time interval are calculated and those vehicular volumes and variances with common time interval are summed.

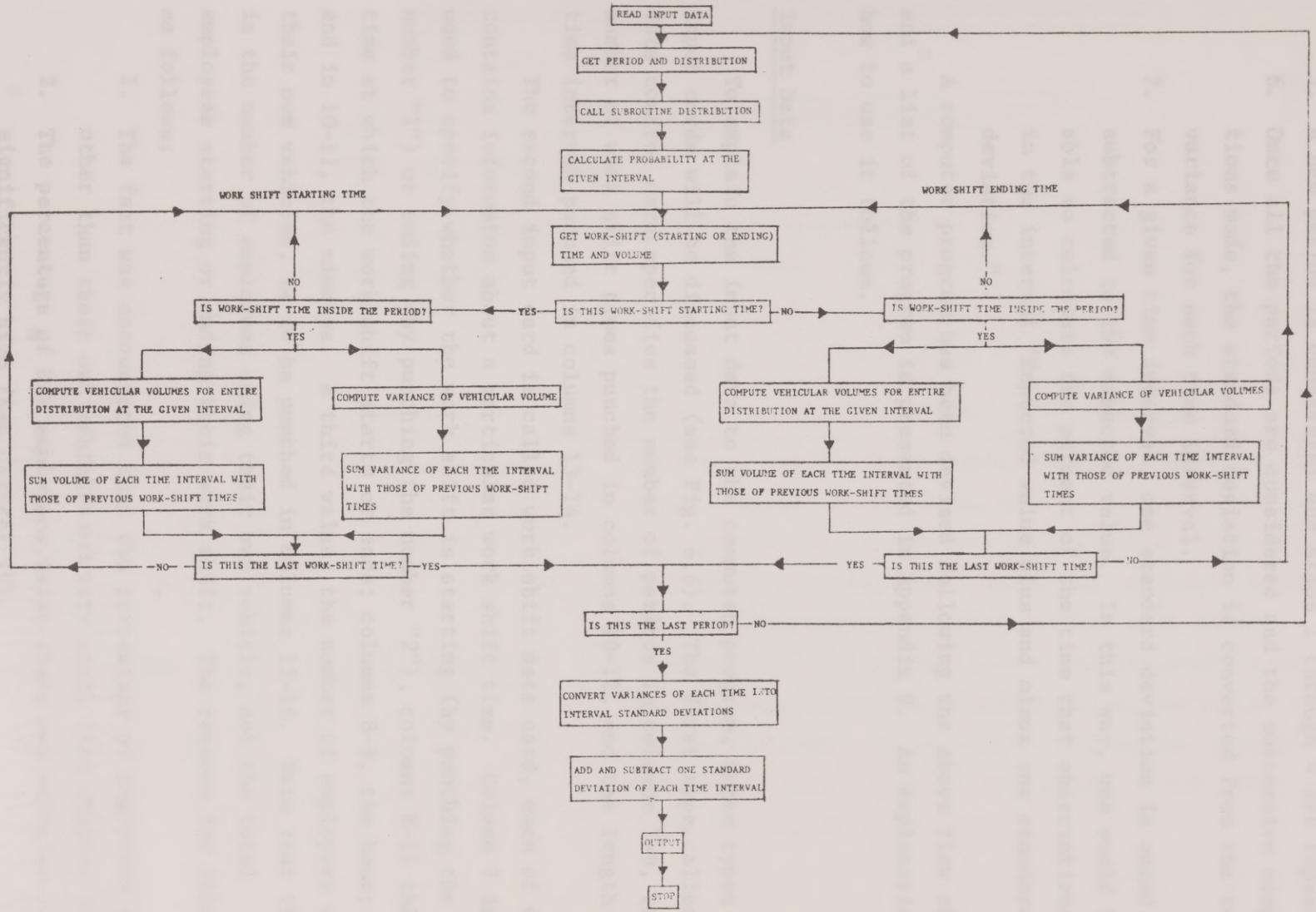


Figure 6.5. Flow Chart of Employee Vehicle Volume Computation.

5. A new period is considered and steps 1 through 4 are repeated.
6. Once all the periods are considered and the successive computations made, the standard deviation is converted from the total variance for each time interval.
7. For a given time interval, one standard deviation is added and subtracted to the expected value. In this way, one would be able to calculate the percent of the time that observations fall in the interval "Expected value plus and minus one standard deviation."

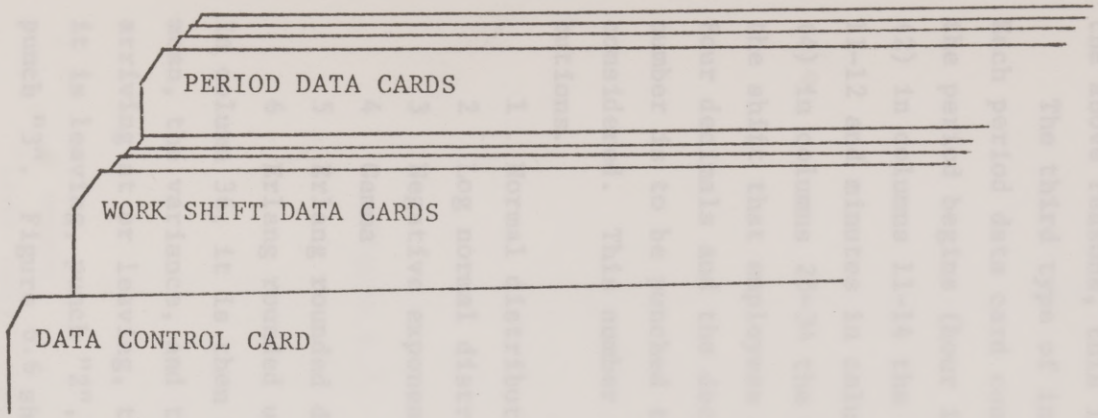
A computer program has been devised following the above flow chart and a list of the program is presented in Appendix B. An explanation of how to use it follows.

Input Data

To explain the input data to the computer program, three types of input cards will be discussed (see Fig. 6.6). The first type, called the data control card, specifies the number of periods in columns 7-9, the number of work shift times punched in columns 10-12, and the length of time interval punched in columns 13-14.

The second input card is called work shift data card, each of which contains informaton about a particular work shift time. Column 7 is used to specify whether the work shift is starting (by punching the number "1") or ending (by punching the number "2"), columns 8-11 the time at which the work shift starts or ends; columns 8-9, the hour; and in 10-11, the minutes. A third value, the number of employees using their own vehicles, is to be punched in columns 12-16. Note that this is the number of employees using their own vehicle, not the total employees starting or ending their work shift. The reasons for this are as follows:

1. The fact was encountered that the percentage of employees using other than their own vehicles was very small (See Chapter IV).
2. The percentage of DFW employees using their own vehicles is significantly high (See Chapter IV).



CARD	FORMAT	DATA
Data control card	6x,2I3,I2	Number of period data cards, number of work shift data cards, length of time interval.
Work shift data cards	6x,I1,2I2,F5.0	1 if work shift is starting or 2 if work shift is ending, work shift starting time (hours and minutes), number of employees starting or ending at that work shift.
Period data cards	6x,4I2,2F10.0,2I1	Time that periods starts,(hours and minutes), time that periods end (hours and minutes), mean, variance, distribution (1 Normal, 2 Lognormal 3 Negative exponential 4 Gamma, 5 Erlang down, 6 Erlang up), 1 for arriving 2 for leaving or 3 for both.

Figure 6.6. Input Data Structure.

Thus, an estimate of the number of employee vehicles entering and leaving the airport in a given interval of time is obtained as the corresponding number of employees who use their own vehicles . Based on the above reasons, this is felt to be a reasonable assumption.

The third type of input data cards are called period data cards. Each period data card contains: (1) in columns 7-10, the time at which the period begins (hour in columns 7-8 and minutes in columns 9-10); (2) in columns 11-14 the time at which the period ends (hour in columns 11-12 and minutes in columns 13-14); (3) in columns 15-24 the mean and (4) in columns 25-34 the standard deviation of the time before and after the shift that employees arrive or leave in that period, respectively. Four decimals and the decimal point are allowed; (6) in column 35 a number is to be punched to indicate the type of distribution to be considered. This number code indicates the following respective distributions.

1 Normal distribution
2 Log normal distribution
3 Negative exponential
4 Gamma
5 Erlang rounded down distribution
6 Erlang rounded up distribution

In column 36, it is then indicated whether this distribution, with the mean, the variance, and the period specified, is to be used for employees arriving at or leaving, the airport. If it is arriving, punch "1"; if it is leaving, punch "2", and if it is for both arriving and leaving, punch "3". Figure 6.6 shows the entire input data structure.

Output

The computer output is shown in Figs. 6.7 through 6.9. In Fig. 6.7 the first part of the output is illustrated. The information about work shifts, is shown as a printout of the original "Work Shift Data Card". In Fig. 6.8 a printout of the period data card is shown. These printouts allow the user to check the data for keypunch errors and data

WORK SHIFTS

	EMPLOYEES	
TIME	STARTING	ENDING
5 0	82	
510	16	
515	33	
520	13	
525	6	
530	95	
535	6	
545	6	
550	10	
555	30	
6 0	586	
6 5	36	
615	42	
625	6	
630	158	
645	16	
7 0	698	
710	20	
715	20	
720	13	
730	341	
735	6	
745	53	
8 0	1022	
815	30	
820	20	
830	498	
845	16	
9 0	188	
930	20	
945	10	
10 0	59	
1015	10	
1030	125	
1045	16	
11 0	89	
1115	16	
1130	33	
1145	10	
12 0	111	
12 5	13	
1210	13	
1215	16	
1230	68	
13 0	79	
1310	10	
1315	66	
1325	10	
1330	46	
1345	6	
14 0	262	
1415	23	
1420	26	
1430	101	

Figure 6.7. Work Shift Information.

PERIODS

BORDERS					
LOWER	UPPER	MEAN	VARIANCE	DISTRIBUTION	WAY
0 0	5 0	22.0732	423.9695	GAMMA	ARRIVING
5 0	9 0	17.4120	269.3503	GAMMA	ARRIVING
9 0	13 0	27.3976	521.6349	GAMMA	ARRIVING
13 0	21 0	26.7309	428.6152	GAMMA	ARRIVING
21 0	24 0	23.5417	304.9913	NEG. EXPONENTIAL	ARRIVING

Figure 6.8. Periods Information.

EMPLOYEE VEHICLE VOLUME

TIME INTERVAL	ARRIVING MINIMUM VOLUME	ARRIVING MEAN VOLUME	ARRIVING MAXIMUM VOLUME	LEAVING MINIMUM VOLUME	LEAVING MEAN VOLUME	LEAVING MAXIMUM VOLUME
015	0	0	0	0	0	0
030	0	0	0	0	0	0
045	0	0	0	0	0	0
1 0	0	0	0	0	0	0
115	0	0	0	0	0	0
130	0	0	0	0	0	0
145	0	0	0	0	0	0
2 0	0	0	0	0	0	0
215	0	0	0	0	0	0
230	0	0	0	0	0	0
245	0	0	0	0	0	0
3 0	0	0	0	0	0	0
315	0	0	0	0	0	0
330	*	*	*	0	0	0
345	*	1	2	0	0	0
4 0	1	3	5	0	0	0
415	5	7	10	0	0	0
430	12	17	21	0	0	0
445	33	40	46	0	0	0
5 0	70	79	87	0	0	0
515	82	92	101	0	0	0
530	129	140	152	0	0	0
545	193	207	221	0	0	0
6 0	370	389	409	0	0	0
615	100	111	121	0	0	0
630	166	179	192	0	0	0
645	215	230	245	0	0	0
7 0	430	450	471	0	0	0
715	162	175	188	0	0	0
730	311	329	347	0	0	0
745	321	340	358	0	0	0
8 0	598	622	647	0	0	0
815	160	173	186	0	0	0
830	280	297	314	0	0	0
845	54	62	70	0	0	0
9 0	94	105	115	0	0	0
915	13	17	21	0	0	0
930	22	27	33	0	0	0
945	31	38	44	0	0	0
10 0	44	51	58	0	0	0
1015	47	54	61	0	0	0
1030	58	66	74	0	0	0
1045	35	42	48	0	0	0
11 0	41	48	55	0	0	0
1115	26	32	37	0	0	0
1130	35	42	48	0	0	0
1145	47	54	62	0	0	0
12 0	60	69	77	0	0	0
1215	35	42	48	0	0	0
1230	40	47	54	0	0	0
1245	42	49	56	0	0	0
13 0	67	75	84	0	0	0
1315	64	72	81	0	0	0
1330	71	79	88	0	0	0
1345	108	119	129	0	0	0
14 0	132	144	156	0	0	0
1415	97	107	117	0	0	0
1430	109	120	131	0	0	0
1445	102	112	123	0	0	0
15 0	114	125	136	0	0	0
1515	60	68	76	0	0	0
1530	73	82	91	0	0	0
1545	68	77	86	0	0	0
16 0	77	86	95	0	0	0
1615	40	47	54	0	0	0
1630	38	44	51	0	0	0
1645	23	28	34	0	0	0
17 0	23	28	33	0	0	0
1715	17	22	26	0	0	0
1730	25	30	35	0	0	0
1745	28	33	39	0	0	0
18 0	27	32	36	0	0	0
1815	11	15	18	0	0	0
1830	15	19	24	0	0	0
1845	14	18	22	0	0	0
19 0	14	18	22	0	0	0
1915	18	23	28	0	0	0
1930	33	39	46	0	0	0
1945	51	59	67	0	0	0
20 0	51	59	66	0	0	0
2015	6	9	12	0	0	0
2030	9	12	16	0	0	0
2045	17	22	26	0	0	0
21 0	26	32	38	0	0	0
2115	36	43	49	0	0	0
2130	61	69	77	0	0	0
2145	13	17	21	0	0	0
22 0	24	30	35	0	0	0
2215	0	0	0	0	0	0
2230	0	0	0	0	0	0
2245	0	0	0	0	0	0
23 0	0	0	0	0	0	0
2315	0	0	0	0	0	0
2330	0	0	0	0	0	0
2345	0	0	0	0	0	0
24 0	0	0	0	0	0	0

Figure 6.9. Calculated DFW Employee Volumes

accuracy. Figure 6.9, the last part of the output, contains the results of the analysis. For each time interval a range of volumes is shown whose boundaries are the minimum volume (mean minus one standard deviation), the mean, and the maximum volume (mean plus one standard deviation). These values are printed out for DFW employees arriving at and leaving the airport.

Calibration of the Model

In order to estimate the total number of employees who begin and end each work shift for input to the model, the same proportion of employees on each work shift as obtained in the survey sample was applied to the total DFW employees.

The model was then used to obtain estimates of the number of employees entering and leaving the airport in each 15-minute interval throughout the day. Equations (1) through (5) were used for this purpose. The results were then compared with the 15-minute manual counts made in the May 1975 survey (Ref. 4), and the volume of DFW employees arriving at or leaving the airport who drive their own vehicles. This latter volume calculation, called the "survey-response volume," was made according to the responses to questions of the Employee Travel Survey (see Chapter III) on the time that people arrive at or leave for work and their mode of travel to the airport.

Tables 6.1 and 6.2 show the survey-response volumes, the model estimates, and the traffic count volumes arriving at and leaving the airport, respectively.

Comparing model estimates of the volumes with the count volume in Tables 6.1 and 6.2, it can be noted that the two values differ substantially for given time intervals. The explanation for these differences stems from a misunderstanding of the on-airport travel patterns of airport employees on the part of the project staff prior to conducting the survey in May 1975. The staff was under the impression that employees used only the service road system (see Chapter III) for their on-airport access to work. It was not until the survey was underway that it was discovered that employees also use the main "spine highway" as well. The

TABLE 6.1. COMPARISON OF DFW EMPLOYEE VOLUME FROM DIFFERENT SOURCES (ARRIVING AT THE AIRPORT).

TIME INTERVAL	SURVEY RESPONSE VOLUME	MODEL VOLUME			COUNT VOLUME	TIME INTERVAL	SURVEY RESPONSE VOLUME	MODEL VOLUME			COUNT VOLUME
		MINIMUM	MEAN	MAXIMUM				MINIMUM	MEAN	MAXIMUM	
601-615	107	100	111	121	68	1401-1415	111	97	107	117	160
616-630	272	166	179	192	116	1416-1430	202	109	120	131	172
631-645	207	215	230	245	169	1431-1445	103	102	112	123	107
646-700	466	430	450	471	143	1446-1500	148	114	125	136	93
701-715	210	162	179	188	108	1501-1515	66	60	68	76	90
716-730	433	311	329	347	124	1516-1530	120	73	82	91	81
731-745	280	321	340	358	119	1531-1545	70	68	77	86	69
746-800	751	598	622	647	148	1546-1600	124	77	86	95	82
801-815	173	160	173	186	110	1601-1615	49	40	47	54	69
816-830	338	280	297	314	79	1616-1630	70	38	44	51	71
831-845	54	54	62	70	62	1631-1645	25	23	28	34	65
846-900	99	94	105	115	57	1646-1700	21	23	28	33	64
901-915	8	13	17	21	58	1701-1715	4	17	22	26	40
916-930	66	22	27	33	48	1716-1730	54	25	30	35	43
931-945	8	31	38	44	104	1731-1745	33	28	33	39	38
946-1000	132	44	51	58	123	1746-1800	29	27	32	38	39
1001-1015	41	47	54	61	93	1801-1815	13	11	15	18	48
1016-1030	41	58	66	74	72	1816-1830	33	15	19	24	39
1031-1045	58	35	42	48	86	1831-1845	8	14	18	22	41
1046-1100	58	41	48	55	63	1846-1900	8	14	18	22	19
1101-1115	25	26	32	37	89	1901-1915	4	18	23	28	43
1116-1130	82	35	42	48	92	1916-1930	25	33	39	46	42
1131-1445	66	47	54	62	80	1931-1945	0	51	59	67	46
1146-1200	66	60	69	77	82	1946-2000	8	51	59	66	18
1201-1215	45	35	42	48	86	2001-2015	8	6	9	12	16
1216-1230	66	40	47	54	78	2016-2030	8	9	12	16	28
1231-1245	37	42	49	56	96	2031-2045	25	17	22	26	26
1246-1300	91	67	75	84	97	2046-2100	45	26	32	38	31
1301-1315	54	64	72	81	99	2101-2115	45	36	43	49	38
1316-1330	173	71	79	88	128	2116-2130	107	61	69	77	48
1331-1345	91	108	119	129	125	2131-2145	37	13	17	21	37
1346-1400	206	132	144	156	146	2146-2200	54	24	30	35	43

TABLE 6.2. COMPARISON OF DFW EMPLOYEE VOLUME FROM DIFFERENT SOURCES (LEAVING THE AIRPORT)

TIME INTERVAL	SURVEY RESPONSE VOLUME	MODEL VOLUME			COUNT VOLUME	TIME INTERVAL	SURVEY RESPONSE VOLUME	MODEL VOLUME			COUNT VOLUME
		MINIMUM	MEAN	MAXIMUM				MINIMUM	MEAN	MAXIMUM	
0601-0615	123	64	72	81	51	1401-1415	78	68	76	85	113
0616-0630	33	67	75	84	48	1416-1430	54	68	76	85	178
0631-0645	12	46	53	60	45	1431-1445	285	313	331	349	157
0646-0700	78	25	31	36	25	1446-1500	260	150	163	176	209
0701-0715	124	66	74	83	118	1501-1515	318	262	279	295	162
0716-0730	99	75	84	93	144	1516-1530	186	131	143	155	153
0731-0745	74	86	96	105	79	1531-1545	313	322	340	358	233
0746-0800	181	70	78	87	94	1546-1600	206	147	159	172	84
0801-0815	41	91	101	111	38	1601-1615	280	311	328	346	87
0816-0830	37	59	67	75	55	1616-1630	210	149	162	174	122
0831-0845	4	30	36	42	41	1631-1645	516	450	471	493	145
0846-0900	12	13	17	21	42	1646-1700	260	199	213	228	78
0901-0915	8	11	14	18	37	1701-1715	454	458	479	501	200
0916-0930	58	12	16	19	39	1716-1730	280	201	216	230	122
0931-0945	25	25	31	36	43	1731-1745	223	153	165	178	78
0946-1000	4	18	23	28	41	1746-1800	41	67	76	85	78
1001-1015	4	7	11	14	40	1801-1815	153	93	104	114	58
1016-1030	8	2	4	6	31	1816-1830	33	43	50	57	61
1031-1045	12	3	5	7	38	1831-1845	62	62	70	78	60
1046-1100	0	3	6	8	39	1846-1900	41	24	30	35	60
1101-1115	0	2	5	7	37	1901-1915	66	91	101	111	127
1116-1130	12	1	3	4	73	1916-1930	82	38	45	52	112
1131-1145	4	0	3	4	59	1931-1945	49	23	28	33	56
1146-1200	16	0	2	3	75	1946-2000	33	20	25	30	61
1201-1215	21	5	8	10	61	2001-2015	54	28	34	39	46
1216-1230	16	6	9	12	47	2016-2030	21	26	32	37	46
1231-1245	0	5	8	10	50	2031-2045	45	37	43	49	49
1246-1300	0	2	5	7	36	2046-2100	33	27	32	38	81
1301-1315	4	7	10	13	13	2101-2115	87	50	58	60	100
1316-1330	8	18	23	28	52	2116-2130	49	48	56	63	47
1331-1345	62	39	45	52	87	2131-2145	87	54	61	69	64
1346-1400	21	27	32	38	91	2146-2200	37	48	55	62	47

precise proportion of employees who use the spine highway is not known at present (there are plans in the project to conduct a mini-survey to estimate this proportion as a function of time of day). However, it is expected to be significant and a major explanatory factor for the difference between the model estimate and the service road traffic counts.

One other piece of vital information that should help explain the above differences is employee vehicle-occupancy data. The model estimates in Tables 6.1 and 6.2 are based on an assumed employee occupancy of one. The actual figure (which will be obtained from a mini-survey as a later part of this project, but not reported in this thesis) is almost certainly greater than one. Figures 6.10 and 6.11 show graphically the comparison of the model estimates and the count volume for DFW employees arriving at and leaving the airport, respectively.

Once the above two factors, i.e., the proportion of employee vehicles that use the spine road instead of the service road and the average employee vehicle occupancy, are obtained and applied to the model estimates, it is expected that there will be closer agreement between the model estimates and the service road counts.

Comparing, now, the survey response volume with the model volumes, it can be noted that in almost all the cases the survey response volume is near if not inside the interval of the model volume. This close agreement is certainly expected since the model parameters are based on the survey response. This comparison only verifies that the model itself was accurately defined. The real validation of the model involves the above comparison of model estimates with actual traffic counts.

Similar conclusions are applied for the case of DFW employees leaving the airport.

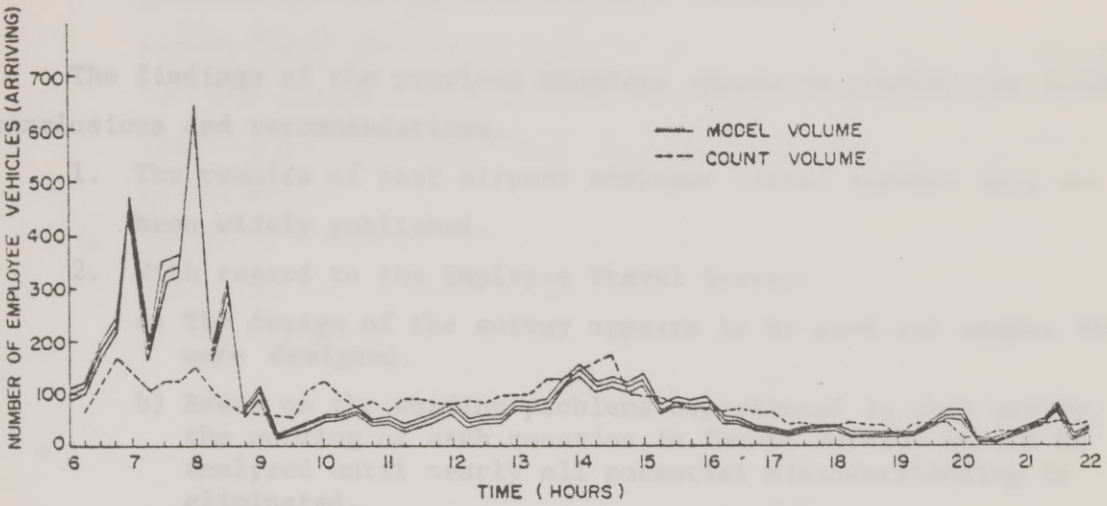


Figure 6.10. Calculated and Counted Employee Volumes (Arriving at the Airport)

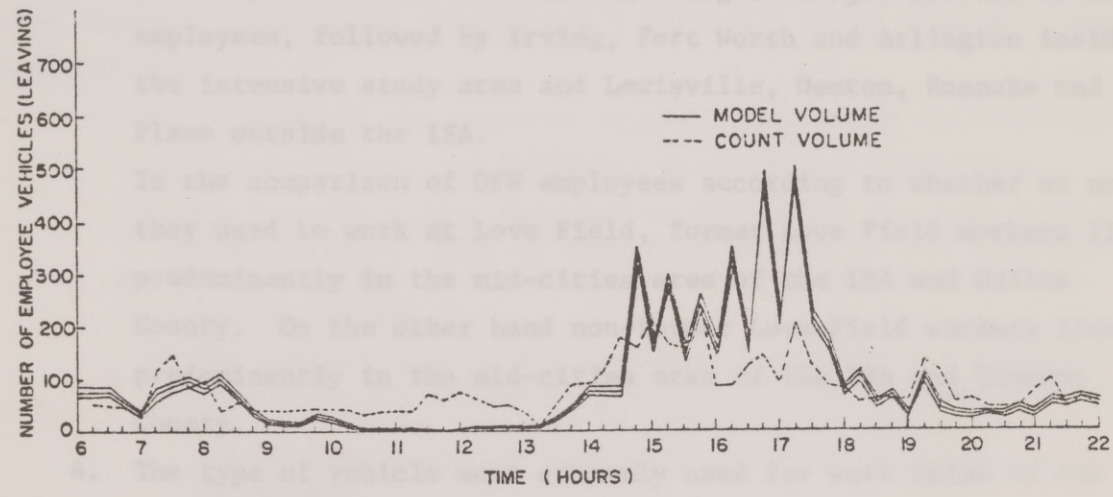


Figure 6.11. Calculated and Counted Employee Volumes (Leaving the Airport)

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

The findings of the previous chapters appear to justify the following conclusions and recommendations.

1. The results of past airport employee travel surveys have not been widely published.
2. With regard to the Employee Travel Survey:
   a) The design of the survey appears to be good and usable data were designed.
   b) Based on the wording problems experienced in this survey, the wording of each question in future surveys should be analyzed until nearly all potential misunderstanding is eliminated.
   c) On questions allowing multiple responses, every response should be analyzed so that all response possibilities are covered. In the survey question regarding occupation, for example, all types of occupation existing at the DFW airport were not covered by the response choices.
   d) The rate of response was 24.24 percent.
3. To facilitate locating DFW employee residences in the study area, DFW employees were grouped by zones designated by the North Central Texas Council of Governments, and also at the city level. The city of Dallas exhibited the largest single portion of DFW employees, followed by Irving, Fort Worth and Arlington inside the intensive study area and Lewisville, Denton, Roanoke and Plano outside the ISA.

   In the comparison of DFW employees according to whether or not they used to work at Love Field, former Love Field workers live predominantly in the mid-cities area of the ISA and Dallas County. On the other hand non-former Love Field workers live predominantly in the mid-cities area of the ISA and Tarrant County.
4. The type of vehicle most commonly used for work trips is the employee's own vehicle.
5. In determining the theoretical distributions that replicate the way that DFW employees arrive or leave the airport before or after the work shift starting or ending time, respectively, the

goodness-of-fit test used was the Kolmogorov-Smirnov Test, and it was found that Gamma was the most satisfactory distribution for both cases. Negative exponential and Erlang round up (particular cases of Gamma) were the next most satisfactory distributions.

6. In the development of a methodology to estimate the volume of employees the following features are to be considered:

   a) the variance of the total expected volume in a time slice $(t, t + \Delta t)$ is the sum of the variances of the expected value of each work shift curve, under the assumption that the values for the various work shifts in the time slice $(t, t + \Delta t)$ are stochastically independent, and that the total volume in a time slice is independent of the volume in other time slices.

   b) The variance of the number of employees in each time slice from each work shift is a rough variance determined according to the formula:

$$\text{Var}\{N_i(t, t + \Delta t) = N_i\{P_i(t, t + \Delta t)\}\{1 - P_i(t, t + \Delta t)\}$$

This calculation is based on the assumptions that each of the DFW employees with a common work shift time (starting or ending) has the same probability $P(t, t + \Delta t)$ of falling into interval $(t, t + \Delta t)$, and that each employee essentially constitutes a Bernoulli trial with that same probability.

7. With regard to the computer program constructed to determine vehicular volume, the following features are summarized:

   a) The program allows the user to divide the day into different time periods. This is important because it has been shown that arriving or departing characteristics are different during the day.

   b) The program also allows the user to specify the length of a time slice for analysis, the type of distribution, and the choice of using the type of distribution with different means and variances and for employees arriving at and/or leaving the airport.

   c) The program can be extended in use to quantities other than employee travel volumes and entities other than the DFW airport. The only required condition is similar characteristics and behavior in time.

d) As part of the input data, the probability distribution of how the employees arrived at or leave the airport relative to their work shift times are required. This is a disadvantage because of the need for estimation of these values. However, this is considered minor compared to the benefits to be derived from the model.

e) Obtaining another required input data item, the vehicular volume, also can create problems. In the case of DFW employees, where it was found that they drive their own vehicles approximately 90% of the time, obtaining the vehicular volume is a simple task. For those cases where there is more than one type of vehicle used significantly, the determination of the vehicular volume can be found, but with greater difficulty.

f) The program is limited to only 5 distributions. These distributions were selected as the most common ones for vehicular volumes of those DFW employees driving their vehicles. Significant vehicular volumes involving other types of vehicles may have distributions other than the ones specified previously.

8. In order to verify that the model itself is accurately defined, the survey response volume was compared with the model volumes. Since the model parameters are based on the survey response, a close agreement was found.

9. The only source for validating the model was the service road traffic count made in May, 1975, but because of the lack of information on the proportion of employees that use the service road and employee vehicle occupancy, the complete validation could not be accomplished in this thesis.

10. Further research concerning the methodology is necessary in order to investigate, for example:

a) The advantages of utilizing the methodology in other cases where, for a common work shift time (starting or ending), different types of traffic are being noted. These different types of traffic might have different distributions or the same distribution with different mean and variance. As an example, there is the possibility of two significant populations of employees, one driving their own vehicles and the other carpooling, each one with a different distribution.

b) It is recommended that a mini-survey be conducted to determine the proportion of employees who use the spine highway

as distinguished from those who use the service roads and the employee vehicle occupancy statistics. Both of the above data items should be obtained as a function of time of day.

APPENDIX A

TABLE A.1. DFW EMPLOYEES BY ZONE

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
	67	2.06	99	4	0.12	167	2	0.06
45	1	0.03	100	4	0.12	168	3	0.09
50	1	0.03	101	5	0.15	169	4	0.12
51	1	0.03	102	3	0.09	170	4	0.12
52	4	0.12	103	4	0.12	171	5	0.15
53	6	0.19	104	11	0.34	172	3	0.09
54	12	0.37	105	1	0.03	173	3	0.09
55	6	0.19	106	4	0.12	174	8	0.25
56	4	0.12	108	7	0.22	175	18	0.55
57	2	0.06	110	2	0.06	176	11	0.34
58	17	1.52	111	5	0.15	177	3	0.09
59	1	0.03	113	2	0.06	179	11	0.34
60	2	0.06	114	2	0.06	180	3	0.09
61	5	0.15	115	13	0.40	181	9	0.28
62	12	0.37	117	4	0.12	183	1	0.03
63	1	0.03	118	4	0.12	185	3	0.09
64	1	0.03	119	5	0.15	187	2	0.06
65	14	0.43	120	2	0.06	188	2	0.06
66	10	0.31	121	5	0.15	189	1	0.03
67	12	0.37	122	1	0.03	190	11	0.34
68	3	0.09	123	1	0.03	191	5	0.15
69	7	0.22	124	3	0.09	192	6	0.19
70	27	0.83	125	1	0.03	193	16	0.49
71	14	0.43	126	3	0.09	194	5	0.15
72	2	0.06	127	5	0.15	195	5	0.15
73	1	0.03	129	2	0.06	196	1	0.03
74	11	0.34	130	1	0.03	198	2	0.06
75	10	0.31	131	7	0.22	199	3	0.09
76	2	0.06	132	9	0.28	200	12	0.37
78	2	0.06	136	2	0.06	202	2	0.06
79	1	0.03	137	2	0.06	203	1	0.03
80	3	0.09	138	2	0.06	204	3	0.09
81	4	0.12	139	1	0.03	205	9	0.28
82	4	0.12	141	3	0.09	206	2	0.06
84	1	0.03	142	1	0.03	207	11	0.34
85	2	0.06	143	2	0.06	208	11	0.34
86	3	0.09	146	1	0.03	211	1	0.03
87	1	0.03	147	1	0.03	213	9	0.28
88	2	0.06	149	1	0.03	214	3	0.09
89	2	0.06	151	1	0.03	215	3	0.09
90	25	0.77	152	3	0.09	216	8	0.25
91	7	0.22	153	9	0.28	217	16	0.49
92	2	0.06	155	1	0.03	221	13	0.40
93	2	0.06	156	8	0.25	222	8	0.25
94	5	0.15	157	4	0.12	223	13	0.40
95	27	0.83	158	2	0.06	224	9	0.28
96	5	0.15	159	1	0.03	225	2	0.06
97	7	0.22	165	1	0.03	226	1	0.03
98	2	0.06	166	3	0.09	228	1	0.03

TABLE A.1. (CONTINUED)

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
229	3	0.09	317	1	0.03	391	11	0.34
233	1	0.03	324	1	0.03	392	3	0.09
234	1	0.03	331	2	0.06	393	1	0.03
235	44	1.36	332	2	0.06	394	15	0.46
236	3	0.09	333	4	0.12	395	13	0.40
237	24	0.74	335	2	0.06	396	2	0.06
238	2	0.06	336	2	0.06	397	1	0.03
240	9	0.28	340	4	0.12	401	21	0.65
241	1	0.03	342	3	0.09	402	40	1.23
242	56	1.73	345	3	0.09	403	55	1.70
243	56	1.73	346	8	o.25	404	2	0.06
244	1	0.03	347	16	0.49	408	1	0.03
245	7	0.22	348	27	0.83	410	29	0.89
246	6	0.19	349	13	0.40	411	27	0.33
247	5	0.15	350	40	1.23	412	5	0.15
248	2	0.06	351	16	0.49	413	4	0.12
249	1	0.03	352	4	0.12	414	4	0.12
253	1	0.03	353	19	0.59	414	6	0.19
255	4	0.12	354	21	0.65	416	10	0.31
257	1	0.03	355	3	0.09	418	5	0.15
259	1	0.03	356	3	0.09	419	4	0.12
260	1	0.03	357	5	0.15	420	1	0.03
261	8	0.25	358	37	1.14	421	4	0.12
262	71	2.19	360	3	0.09	422	2	0.06
263	41	1.27	361	3	0.09	424	1	0.03
264	24	0.74	362	2	0.06	429	2	0.06
265	52	1.60	363	6	0.19	430	2	0.06
269	8	0.25	365	4	0.12	432	5	0.15
271	1	0.03	367	20	0.62	433	3	0.09
272	17	0.52	368	115	3.55	434	3	0.09
273	15	0.46	369	1	0.03	436	1	0.03
274	15	0.46	372	22	0.68	438	1	0.03
275	1	0.03	373	1	0.03	439	9	0.25
276	4	0.46	374	163	5.03	440	1	0.03
277	1	0.03	375	49	1.51	444	2	0.06
278	10	0.31	376	17	0.52	445	1	0.03
279	6	0.19	377	16	0.49	447	7	0.22
280	32	0.99	378	29	0.89	448	4	0.12
281	23	0.71	379	3	0.09	450	2	0.06
282	50	1.54	380	98	3.02	451	7	0.22
283	24	0.74	381	8	0.25	452	3	0.09
284	23	0.71	382	4	0.12	453	1	0.03
285	12	0.37	383	3	0.09	454	6	0.19
286	17	0.52	384	2	0.06	455	2	0.06
287	26	0.80	385	15	0.46	461	1	0.03
288	34	1.05	387	6	0.19	463	1	0.03
289	15	0.46	388	12	0.37	464	1	0.03
290	29	0.89	389	12	0.37	465	1	0.03
291	8	0.25	390	25	0.77	466	6	0.19

TABLE A.1. (CONTINUED)

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
467	1	0.03	523	1	0.03	621	2	0.06
468	1	0.03	528	2	0.06	623	1	0.03
469	3	0.09	529	2	0.06	630	1	0.03
471	4	0.12	532	2	0.06	631	1	0.03
472	3	0.09	533	2	0.06	634	2	0.06
474	2	0.06	535	2	0.06	636	1	0.03
478	4	0.12	536	7	0.22	640	2	0.06
480	1	0.03	537	1	0.03	651	1	0.03
482	1	0.03	539	2	0.06	660	1	0.03
483	3	0.09	542	3	0.09	669	1	0.03
484	3	0.09	544	1	0.03	677	1	0.03
496	31	0.96	546	2	0.06	686	1	0.03
497	139	4.29	547	1	0.03	700	5	0.15
498	4	0.12	550	2	0.06	701	3	0.09
499	28	0.86	551	1	0.03	702	5	0.15
500	3	0.09	552	1	0.03	703	2	0.06
501	4	0.12	555	1	0.03	704	5	0.15
503	4	0.12	557	1	0.03	705	2	0.06
507	4	0.12	572	1	0.03	706	1	0.03
508	1	0.03	578	1	0.03	709	6	0.19
511	6	0.19	580	1	0.03	710	3	0.09
512	1	0.03	583	2	0.06	711	1	0.03
513	13	0.40	596	3	0.09	712	6	0.18
515	3	0.09	598	1	0.03	715	1	0.03
516	4	0.12	602	1	0.03	717	2	0.06
519	2	0.04	608	1	0.03	718	2	0.06
520	11	0.34	613	1	0.03	719	2	0.06
521	1	0.03	619	1	0.03	722	3	0.09
522	13	0.40	620	1	0.03	733	1	0.03

TABLE A.2. FORMER LOVE FIELD WORKER DFW EMPLOYEES BY ZONE

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
	38	1.17	105	1	0.03	177	2	0.06
45	1	0.03	106	1	0.03	179	10	0.31
51	1	0.03	108	5	0.16	180	2	0.06
52	4	0.12	110	2	0.06	181	9	0.27
53	3	0.09	111	4	0.12	183	1	0.03
54	12	0.37	113	2	0.06	185	3	0.09
55	3	0.09	114	2	0.06	187	2	0.06
56	3	0.09	115	8	0.25	188	1	0.03
57	1	0.03	117	4	0.12	189	1	0.03
58	15	0.46	118	4	0.12	190	8	0.25
59	1	0.03	119	5	0.16	191	4	0.12
60	1	0.03	120	1	0.03	192	3	0.09
61	3	0.09	121	4	0.12	193	10	0.31
62	11	0.34	122	1	0.03	194	4	0.12
63	1	0.03	124	3	0.09	195	3	0.09
64	1	0.03	126	2	0.06	196	1	0.03
65	13	0.40	127	4	0.12	198	1	0.03
66	9	0.28	129	1	0.03	199	1	0.03
67	11	0.34	131	5	0.16	200	8	0.25
68	2	0.06	132	7	0.22	202	1	0.03
69	6	0.19	136	1	0.03	203	1	0.03
70	19	0.59	137	2	0.06	204	3	0.09
71	9	0.28	138	2	0.06	205	6	0.19
72	1	0.03	139	1	0.03	207	7	0.22
74	10	0.31	141	2	0.06	208	6	0.19
75	10	0.31	142	1	0.03	213	6	0.19
76	2	0.06	143	2	0.06	214	3	0.09
78	2	0.06	146	1	0.03	215	1	0.03
81	1	0.03	149	1	0.03	216	4	0.12
82	3	0.09	151	1	0.03	217	7	0.22
85	2	0.06	152	2	0.06	221	4	0.12
86	2	0.06	153	9	0.28	222	2	0.06
87	1	0.03	155	1	0.03	223	11	0.34
88	2	0.06	156	6	0.19	224	3	0.09
90	20	0.62	157	1	0.03	226	1	0.03
91	6	0.19	158	1	0.03	228	1	0.03
92	2	0.06	159	1	0.03	229	3	0.09
93	1	0.03	165	1	0.03	235	23	0.71
95	18	0.56	167	2	0.06	237	12	0.37
96	3	0.09	168	1	0.03	238	1	0.03
97	5	0.16	169	2	0.06	240	8	0.25
98	2	0.06	170	3	0.09	242	34	1.05
99	3	0.09	171	4	0.12	243	30	0.93
100	4	0.12	172	2	0.06	244	1	0.03
101	5	0.16	173	3	0.09	245	3	0.09
102	2	0.06	174	6	0.18	246	4	0.12
103	4	0.12	175	14	0.43	247	2	0.06
104	8	0.25	176	8	0.24	248	2	0.06

TABLE A.2. (CONTINUED)

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
249	1	0.03	358	20	0.62	484	2	0.06
253	1	0.03	361	2	0.06	496	20	0.62
255	3	0.09	363	2	0.06	497	97	2.99
257	1	0.03	365	1	0.03	498	2	0.06
259	1	0.03	367	11	0.34	499	21	0.65
260	1	0.03	368	46	1.42	500	3	0.09
261	8	0.25	372	4	0.12	501	2	0.06
262	30	0.93	374	72	2.22	503	3	0.09
263	27	0.83	375	26	0.80	507	2	0.06
264	13	0.40	376	5	0.16	511	3	0.09
265	34	1.05	377	7	0.22	513	8	0.25
269	4	0.12	378	16	0.49	515	2	0.06
271	1	0.03	380	48	1.48	516	4	0.12
272	13	0.40	381	3	0.09	519	2	0.06
273	9	0.28	382	1	0.03	520	8	0.25
274	15	0.46	387	2	0.06	521	1	0.03
276	3	0.09	388	4	0.12	522	10	0.31
277	1	0.03	389	2	0.06	523	1	0.03
278	9	0.28	390	2	0.06	528	2	0.06
279	6	0.19	391	2	0.06	529	1	0.03
280	23	0.71	392	1	0.03	532	1	0.03
281	18	0.56	394	5	0.16	533	1	0.03
282	43	1.33	395	6	0.19	535	2	0.02
283	21	0.65	397	1	0.03	536	4	0.12
284	21	0.65	401	10	0.31	537	1	0.03
285	10	0.31	402	14	0.43	539	2	0.06
286	14	0.43	403	15	0.46	542	3	0.12
287	21	0.65	410	5	0.16	546	2	0.06
288	27	0.83	411	9	0.28	547	1	0.03
289	14	0.43	416	1	0.03	550	2	0.06
290	20	0.62	418	1	0.03	551	1	0.03
291	8	0.25	419	1	0.03	552	1	0.03
333	1	0.03	420	1	0.03	555	1	0.03
336	1	0.03	429	2	0.06	557	1	0.03
340	3	0.09	430	1	0.03	572	1	0.03
342	1	0.03	432	1	0.03	580	1	0.03
345	2	0.06	433	1	0.03	583	2	0.06
346	3	0.09	438	1	0.03	596	2	0.06
347	6	0.19	439	1	0.03	598	1	0.03
348	9	0.28	445	1	0.03	613	1	0.03
349	4	0.12	448	4	0.12	619	1	0.03
350	8	0.25	451	2	0.06	620	1	0.03
351	11	0.34	452	2	0.06	621	1	0.03
352	1	0.03	454	2	0.06	623	1	0.03
353	10	0.31	455	1	0.03	630	1	0.03
354	14	0.43	466	1	0.03	631	1	0.03
355	2	0.06	468	1	0.03	634	2	0.06
356	1	0.03	472	2	0.06	640	2	0.06
357	3	0.09	478	1	0.03	660	1	0.03

TABLE A.2. (CONTINUED)

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
669	1	0.03	704	1	0.03	715	1	0.03
677	1	0.03	705	2	0.06	717	2	0.06
700	5	0.16	706	1	0.03	718	1	0.03
701	2	0.06	709	5	0.16	719	2	0.06
702	4	0.12	710	1	0.03	722	2	0.06
703	2	0.06	712	1	0.03	733	1	0.03

TABLE A.3. NON-LOVE FIELD WORKER DFW EMPLOYEES BY ZONE

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
0	24	0.74	132	2	0.06	241	1	0.03
50	1	0.03	136	1	0.03	242	21	0.65
53	2	0.06	141	1	0.03	243	26	0.80
55	3	0.09	152	1	0.03	245	4	0.12
56	1	0.03	156	2	0.06	246	2	0.06
57	1	0.03	157	3	0.09	247	3	0.09
60	1	0.03	168	2	0.06	262	41	1.27
61	2	0.06	169	1	0.03	263	13	0.40
62	1	0.03	170	1	0.03	264	11	0.34
65	1	0.03	171	1	0.03	265	17	0.52
66	1	0.03	172	1	0.03	269	3	0.09
67	1	0.03	174	2	0.06	272	4	0.12
68	1	0.03	175	4	0.12	273	6	0.19
69	1	0.03	176	3	0.09	275	1	0.03
70	8	0.25	177	1	0.03	276	1	0.03
71	5	0.16	179	1	0.03	278	1	0.03
72	1	0.03	180	1	0.03	280	9	0.28
73	1	0.03	188	1	0.03	281	5	0.16
74	1	0.03	190	3	0.09	282	7	0.22
79	1	0.03	191	1	0.03	283	3	0.09
80	3	0.09	192	3	0.09	284	2	0.06
81	3	0.09	193	6	0.19	285	2	0.06
82	1	0.03	194	1	0.03	286	3	0.09
84	1	0.03	195	2	0.06	287	5	0.16
86	1	0.03	199	2	0.06	288	7	0.22
89	2	0.06	200	4	0.12	289	1	0.03
90	5	0.16	202	1	0.03	290	7	0.22
91	1	0.03	205	2	0.06	317	1	0.03
93	1	0.03	206	2	0.06	324	1	0.03
95	9	0.28	207	4	0.12	331	2	0.06
96	2	0.06	208	5	0.16	332	2	0.06
97	1	0.03	211	1	0.03	333	3	0.09
99	1	0.03	213	3	0.09	335	2	0.06
102	1	0.03	215	2	0.06	336	1	0.03
104	3	0.09	216	4	0.12	340	1	0.03
106	3	0.09	217	9	0.28	342	2	0.06
108	2	0.06	221	9	0.28	345	1	0.03
111	1	0.03	222	6	0.19	346	4	0.12
115	5	0.16	223	2	0.06	347	9	0.28
120	1	0.03	224	6	0.19	348	18	0.56
121	1	0.03	225	2	0.06	349	9	0.28
123	1	0.03	233	1	0.03	350	29	0.89
125	1	0.03	234	1	0.03	351	5	0.16
126	1	0.03	235	20	0.62	352	3	0.09
127	1	0.03	236	1	0.03	353	9	0.28
129	1	0.03	237	11	0.34	354	7	0.22
130	1	0.03	238	1	0.03	355	1	0.03
131	2	0.06	248	2	0.03	356	2	0.06

TABLE A.3. (CONTINUED)

ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL	ZONE	SAMPLE FREQUENCY	% OF TOTAL
357	2	0.06	410	24	0.74	482	1	0.03
358	17	0.52	411	18	0.56	483	3	0.09
360	3	0.09	412	5	0.16	484	1	0.03
361	1	0.03	413	4	0.12	496	11	0.34
362	2	0.06	414	4	0.12	497	39	1.20
363	4	0.12	415	6	0.19	498	2	0.06
365	3	0.09	416	9	0.28	499	7	0.22
367	0	0.28	418	4	0.12	501	1	0.03
368	68	2.15	419	3	0.09	503	1	0.03
369	1	0.03	421	3	0.09	507	2	0.06
372	17	0.52	422	2	0.06	508	1	0.03
373	1	0.03	424	1	0.03	511	3	0.09
374	83	2.56	430	1	0.03	512	1	0.03
375	23	0.71	432	4	0.12	513	5	0.16
376	12	0.37	433	2	0.06	515	1	0.03
377	9	0.28	434	3	0.09	520	3	0.09
378	13	0.40	436	1	0.03	522	2	0.06
379	2	0.06	439	7	0.22	529	1	0.03
380	48	1.48	440	1	0.03	532	1	0.03
381	5	0.16	444	2	0.06	533	1	0.03
382	3	0.09	447	7	0.22	536	3	0.09
383	3	0.09	450	2	0.06	544	1	0.03
384	2	0.06	451	5	0.16	578	1	0.03
385	14	0.43	452	1	0.03	596	1	0.03
387	4	0.12	453	1	0.03	602	1	0.03
388	8	0.25	454	4	0.12	608	1	0.03
389	9	0.28	455	1	0.03	621	1	0.03
390	22	0.68	461	1	0.03	636	1	0.03
391	9	0.28	463	1	0.03	651	1	0.03
392	2	0.06	464	1	0.03	686	1	0.03
393	1	0.03	465	1	0.03	702	1	0.03
394	9	0.28	466	5	0.16	704	3	0.09
395	6	0.19	467	1	0.03	709	1	0.03
396	2	0.06	469	3	0.09	710	1	0.03
401	11	0.34	471	4	0.12	711	1	0.03
402	26	0.80	472	1	0.03	712	5	0.16
403	40	1.23	474	1	0.03	718	1	0.03
404	2	0.06	478	3	0.09	722	1	0.03
408	1	0.03	480	1	0.03			

APPENDIX B

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      PROGRAM EMPDIST ( INPUT,OUTPUT,TAPE1 = INPUT )
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60),JW(3)
      READ 1, NPER,NDATA,INT
C     PRINT 1,NPER,NDATA,INT
    1 FORMAT(6X,2I3,I2)
      PI = 4.0*ATAN(1.0)
      PRINT 19
   19 FORMAT(1H1,/49X,*W O R K   S H I F T S*,//,
     *       58X,*EMPLOYEES          *,//,
     *       46X,*TIME    STARTING    ENDING*,//)
      DO 77 J=1,NDATA
      READ 7, IWAY(J),IHOUR(J),MIN(J),EMPL(J)
    7 FORMAT(6X,I1,2I2,F5.0)
      IF(IWAY(J) .EQ. 1) GO TO 101
      IF(IWAY(J) .EQ. 2) GO TO 102
  101 CONTINUE
      PRINT 15,IHOUR(J),MIN(J),EMPL(J)
   15 FORMAT(46X,2I2,2X,F10.0)
      GO TO 77
  102 CONTINUE
      PRINT 16,IHOUR(J),MIN(J),EMPL(J)
   16 FORMAT(46X,2I2,12X,F10.0)
   77 CONTINUE
      PRINT 29
   29 FORMAT(1H1,/53X,*P E R I O D S*,//,
     *       31X,*BORDERS       *,//,
     *       29X,*LOWER  UPPER     MEAN       VARIANCE     DISTRIBUTION
     *    WAY*,//)
      DO 38 M=1,1440
      GAR(M) = 0.0
      GLE(M) = 0.0
      GXV(M) = 0.0
      GVL(M) = 0.0
   38 CONTINUE
      DO 11 N=1,NPER
      READ 5, IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,IDIST,IW1
    5 FORMAT(6X,4I2,2F10.4,2I1)
      JW(1) = 10H ARRIVING
      JW(2) = 10H  LEAVING
      JW(3) = 10HARR.-LEA.
      IF(IDIST .EQ. 1) GO TO 5010
      IF(IDIST .EQ. 2) GO TO 5020
      IF(IDIST .EQ. 3) GO TO 5030
      IF(IDIST .EQ. 4) GO TO 1040
      IF(IDIST .EQ. 5) GO TO 1050
      IF(IDIST .EQ. 6) GO TO 6010
 5010 CONTINUE
      PRINT 35,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
   35 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),7X,*NORMAL*,5X,A10)
      CALL NORMAL(N)
      GO TO 1060
 5020 CONTINUE
      PRINT 45,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
   45 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),5X,*LOGNORMAL*,4X,A10)
      CALL LOGNRML(N)
      GO TO 1060
 5030 CONTINUE
      PRINT 65,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
```

```
   65 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),2X,*NEG. EXPONENTIAL*A10)
      CALL NEGEXP(N)
      GO TO 1060
 1040 CONTINUE
      PRINT 75,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
   75 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),7X,*GAMMA*,6X,A10)
      CALL GAMMA(N)
      GO TO 1060
 1050 CONTINUE
      PRINT 85,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
   85 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),4X,*ERLANG DOWN*,3X,A10)
      CALL ERLANG(N,0.0)
      GO TO 1060
 6010 CONTINUE
      PRINT 95,IHOUR1,MIN1,IHOUR2,MIN2,XMEAN,VAR,JW(IW1)
   95 FORMAT(30X,2I2,3X,2I2,2(2X,F10.4),6X,*ERLANG UP*,4X,A10)
      CALL ERLANG(N,1.0)
 1060 CONTINUE
C     DO 66 L=1,90
C     PRINT 13,PE(N,L)
C  13 FORMAT(2X,F10.7)
C  66 CONTINUE
      TIME1 = IHOUR1*100 + MIN1
      TIME2 = IHOUR2*100 + MIN2
      DO 22 J=1,NDATA
      IF(IW1 .EQ.3) GO TO 110
      IF(IW1 .NE. IWAY(J)) GO TO 22
  110 CONTINUE
      TIME = IHOUR(J)*100 + MIN(J)
      IF(TIME .LE. TIME1) GO TO 22
      IF(TIME .GT. TIME2) GO TO 22
      IF(IWAY(J) .EQ. 1) GO TO 1090
      IF(IWAY(J) .EQ. 2) GO TO 2010
 1090 CONTINUE
      DO 33 K=1,90
      IHT = IHOUR(J)
      MW = MIN(J)
 7777 CONTINUE
      IF(K .LE. MW) GO TO 9020
      IF(IHT .EQ. 0.0) IHT=24.0
      IHT1 = IHT - 1.0
      IHT = IHT1
      MJ = MW + 60.0
      MW = MJ
      GO TO 7777
 9020 CONTINUE
      M1 = MW - K + 1.0
      IH1 = IHT + 1.0
      ARR(IH1,M1) = EMPL(J)*PE(N,K)
      GAR(IH1,M1) = GAR(IH1,M1) + ARR(IH1,M1)
      Q = 1.0 - PE(N,K)
      XVAR(IH1,M1) = Q*ARR(IH1,M1)
      GXV(IH1,M1) = GXV(IH1,M1) + XVAR(IH1,M1)
C     PRINT 70,IH1,M1,ARR(IH1,M1),GAR(IH1,M1),XVAR(IH1,M1),GXV(IH1,M1)
   70 FORMAT(4X,2I2,2(4X,F10.0),2F10.5)
   33 CONTINUE
      GO TO 22
 2010 CONTINUE
      DO 44 K=1,90
      IHT = IHOUR(J)
```

```
      MW = MIN(J)
      MJ = K + MW
 2222 CONTINUE
      IF(MJ .LT. 60.0) GO TO 9030
      IHT1 = IHT + 1
      IHT = IHT1
      IF(IHT .EQ. 24) IHT=0.0
      MI = MJ - 60
      MJ = MI
      GO TO 2222
 9030 CONTINUE
      IH1 = IHT + 1
      M1 = MJ + 1
      XLEA(IH1,M1) = EMPL(J)*PE(N,K)
      GLE(IH1,M1) = GLE(IH1,M1) + XLEA(IH1,M1)
      Q = 1.0 - PE(N,K)
      VLE(IH1,M1) = Q*XLEA(IH1,M1)
      GVL(IH1,M1) = GVL(IH1,M1) + VLE(IH1,M1)
C     PRINT 114,IH1,M1,XLEA(IH1,M1),GLE(IH1,M1),VLE(IH1,M1),GVL(IH1,M1)
  114 FORMAT(2X,2I2,4F10.0)
   44 CONTINUE
   22 CONTINUE
   11 CONTINUE
      PRINT 39
   39 FORMAT(1H1,/48X,*EMPLOYEE VEHICLE VOLUME*,//,
     *         42X,*A R R I V I N G*,16X,*L E A V I N G*,//,
     *         27X,*TIME  *,2(3X,*MINIMUM*,5X,*MEAN*,4X,*MAXIMUM*),//,
     *         25X,*INTERVAL*,6(4X,*VOLUME*),//)
      J1 = 2.0
      J3 = 60.0
      INT1 = INT
      DO 28 I=1,24
      GO TO 97
   98 CONTINUE
      INT1 = INT
      J1 = J2 + 1
      J3 = 60.0
   97 CONTINUE
      DO 99 J=J1,J3,INT1
      IF(INT .NE. INT1) GO TO 3333
      CAR1 = 0.0
      CAR = 0.0
      CLE1 = 0.0
      CLE = 0.0
      CVAR = 0.0
      CVAR1 = 0.0
      CVLE = 0.0
      CVLE1 = 0.0
 3333 CONTINUE
      J2 = J + INT1 - 1
      NINT = J2
      IF(NINT .GT. 60) NINT=60
      DO 68 K=J,NINT
      CAR1 = CAR + GAR(I,K)
      CAR = CAR1
      CVAR1 = CVAR + GXV(I,K)
      CVAR = CVAR1
      CLE1 = CLE + GLE(I,K)
      CLE = CLE1
      CVLE1 = CVLE + GVL(I,K)
```

```
      CVLE = CVLE1
   68 CONTINUE
      IF(I .NE. 24) GO TO 17
      IF(NINT .LT. 60) GO TO 17
      CAR1 = CAR + GAR(1,1)
      CAR = CAR1
      CVAR1 = CVAR + GXV(1,1)
      CVAR = CVAR1
      CLE1 = CLE + GLE(1,1)
      CLE = CLE1
      CVLE1 = CVLE + GVL(1,1)
      CVLE = CVLE1
      IH2 = 24
      M2 = 00
      GO TO 113
   17 CONTINUE
      IF(J2 .GT. 60) GO TO 99
      IH2 = I - 1.0
      M2 = NINT - 1
  113 CONTINUE
      CAR2 = CAR - SQRT(CVAR)
      CAR3 = CAR + SQRT(CVAR)
      CLE2 = CLE - SQRT(CVLE)
      CLE3 = CLE + SQRT(CVLE)
      PRINT 18,IH2,M2,CAR2,CAR,CAR3,CLE2,CLE,CLE3
   18 FORMAT(27X,2I2,6F10.0)
   99 CONTINUE
      IF(J2 .LE. 60) GO TO 98
      J3 = J2 - 60
      INT1 = J3
      J1 = 1
   28 CONTINUE
      CALL EXIT
      END
```

```
      SUBROUTINE NORMAL(N)
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60),JW(3)
    1 FORMAT(/,41X*>271;PE=S SET TO ZERO*F10.3)
      PI = 4.0*ATAN(1.0)
      CONST = 1.0/SQRT(2.0*PI*VAR)
      AREA = 0.0
      ALAST = 0.0
      FLAST = 0.0
      T = 0.0
      XEXP = -0.5*(T-XMEAN)**2/VAR
             IF( ABS(XEXP) .GT. 271.0 ) GO TO 2010
      FLAST = CONST*EXP(XEXP)
      DO 1020 I=1,90
      DO 1010 J=1,10
      T = T + 0.1
      XEXP = -0.5*(T-XMEAN)**2/VAR
             IF( ABS(XEXP) .GT. 271.0 ) GO TO 2010
      F = CONST*EXP(XEXP)
      AREA = AREA + 0.05*(FLAST+F)
      FLAST = F
1010  CONTINUE
      PE(N,I) = AREA - ALAST
      ALAST = AREA
1020  CONTINUE
      RETURN
2010  CONTINUE
      PRINT 1,XEXP
      DO 81 I=1,90
      PE(N,I) = 0.0
   81 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOGNRML(N)
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60)
    1 FORMAT(/,41X*>271;PE*S SET TO ZERO*F10.3)
      A(2)=ALOG(XMEAN)-0.5*ALOG((VAR/(XMEAN**2))+1.0)
      B(2)=ALOG((VAR/(XMEAN**2))+1.0)
      PI = 4.0*ATAN(1.0)
      CONST=1.0/SQRT(2.0*PI*B(2))
      AREA=0.0
      ALAST=0.0
      FLAST=0.0
      T=0.0
      DO 1020 I=1,90
      DO 1010 J=1,10
      T=T+0.1
      XEXP = -0.5*((ALOG(T)-A(2))**2)/B(2)
             IF( ABS(XEXP) .GT. 271.0 ) GO TO 2010
      F = CONST*EXP(XEXP)/T
      AREA = AREA + 0.05*(FLAST+F)
      FLAST = F
 1010 CONTINUE
      PE(N,I) = AREA - ALAST
      ALAST = AREA
 1020 CONTINUE
      RETURN
 2010 CONTINUE
      PRINT 1,XEXP
      DO 81 I=1,90
      PE(N,I) = 0.0
   81 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE NEGEXP(N)
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60)
    1 FORMAT(/,41X*>271;PE>S SET TO ZERO*F10.3* IN NEGATIVE *
     *           *EXPONENTIAL DISTRIBUTION*)
      A(3)=XMEAN
      T=0.0
      ALAST=0.0
      DO 1010 I=1,90
      T=T+1.0
      XEXP = -T/A(3)
           IF( ABS(XEXP) .GT. 271.0 )  GO TO 2010
      AREA = 1.0 - EXP(XEXP)
      PE(N,I)=AREA-ALAST
      ALAST=AREA
 1010 CONTINUE
      RETURN
 2010 CONTINUE
      PRINT 1,XEXP
      DO 81 I=1,90
      PE(N,I) = 0.0
   81 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GAMMA(N)
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60)
    1 FORMAT(/,41X*(GAMMA),K GT 150 - EXPECTED FREQUENCIES*
     *          * SET TO ZERO IN GAMMA DISTRIBUTION*G13.2)
    2 FORMAT(/,35X,*ATTEMPT TO RAISE EXP GT 271(IE,*F10.3*) IN GAMMA *
     *       *DISTRIBUTION*)
      A(5) = XMEAN/VAR
      B(5) = XMEAN*XMEAN/VAR
             IF( B(5) .GT. 150.0 )   GO TO 2010
      AREA = 0.0
      ALAST = 0.0
      FLAST=0.0
      T = 0.0
      CONST=A(5)/GAMMAF(B(5))
      DO 1020 I=1,90
      DO 1010 J=1,10
      T=T+0.1
      XEXP = -A(5)*T
             IF( ABS(XEXP) .GT. 271.0)  GO TO 2020
      F=CONST*((A(5)*T)**(B(5)-1.0))*EXP(XEXP)
      AREA=AREA+0.05*(FLAST+F)
      FLAST=F
 1010 CONTINUE
      PE(N,I)=AREA-ALAST
      ALAST=AREA
 1020 CONTINUE
      RETURN
 2010 CONTINUE
      PRINT 1, B(5)
      DO 81 I=1,90
      PE(N,I) = 0.0
   81 CONTINUE
      RETURN
 2020 CONTINUE
      PRINT 2, XEXP
      DO 31 I=1,90
      PE(N,I) = 0.0
   31 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ERLANG(N,XROUND)
      COMMON PE(24,90),XMEAN,VAR,A(9),B(9),ARR(24,60),XLEA(24,60),GAR(24
     *,60),GLE(24,60),IWAY(99),IHOUR(99),MIN(99),EMPL(99),XVAR(24,60),VL
     *E(24,60),GXV(24,60),GVL(24,60)
    1 FORMAT(/,35X*(ERLANG),K GT 150(*F10.3*) = EXPECTED FREQUENCIES*
     *          * SET TO ZERO IN ERLANG DISTRIBUTION*)
    2 FORMAT(/,40X,*ATTEMPTED TO SET K EQUAL TO ZERO IN ERLANG*
     *           * DISTRIBUTION*)
    3 FORMAT(/,41X*>271;PE*S SET TO ZERO*F10.3* IN ERLANG DISTRIBUTION*)
      NDIST = XROUND + 6.0
      A(NDIST) = XMEAN/VAR
      IB=XMEAN**2/VAR+XROUND
      B(NDIST) = IB
               IF( B(NDIST) .GT. 150.0)   GO TO 2010
               IF( IB .EQ. 0 ) GO TO 2020
      AREA = 0.0
      ALAST=0.0
      FLAST=0.0
      T = 0.0
      IBM1=IB-1
      IFACT=1
      DO 1010 I=1,IBM1
      IFACT=IFACT*I
 1010 CONTINUE
      CONST=A(NDIST)/IFACT
      DO 1030 I=1,90
      DO 1020 J=1,10
      T=T+0.1
      XEXP = -A(NDIST)*T
               IF( ABS(XEXP) .GT. 271.0 )  GO TO 2030
      F=CONST*((A(NDIST)*T)**IBM1)*EXP(XEXP)
      AREA=AREA+0.05*(FLAST+F)
      FLAST=F
 1020 CONTINUE
      PE(N,I)=AREA-ALAST
      ALAST=AREA
 1030 CONTINUE
      RETURN
 2010 CONTINUE
      PRINT 1, B(NDIST)
      DO 61 I=1,90
      PE(N,I) = 0.0
   61 CONTINUE
      RETURN
 2020 CONTINUE
      PRINT 2
      DO 61 I=1,90
      PE(N,I) = 0.0
   61 CONTINUE
      RETURN
 2030 CONTINUE
      PRINT 3, XEXP
      DO 51 I=1,90
      PE(N,I) = 0.0
   51 CONTINUE
      RETURN
      END
```

```
      FUNCTION GAMMAF(X)

C W.GAUTSCHI,ALGORITHM221,CACM. H.WERNER,R.COLLINGE,MOC15,195-197.
      DATA A00/ 0.99999 99999 9999/
      DATA A01/ 0.42278 43351 0233/
      DATA A02/ 0.41184 03301 6678/
      DATA A03/ 0.08157 69261 24155/
      DATA A04/ 0.07424 89154 19444/
      DATA A05/-0.00026 61865 94953 06/
      DATA A06/ 0.01114 97143 35778/
      DATA A07/-0.00283 64625 20372 8/
      DATA A08/ 0.00206 10918 50225 5/
      DATA A09/-0.00083 75646 85135 17/
      DATA A10/ 0.00037 53650 52263 07/
      DATA A11/-0.00012 14173 48706 32/
      DATA A12/ 0.00002 79832 88993 83/
      DATA A13/-0.00000 30301 90810 28/
C
      Z=X
              IF(X.GT.150.0) GO TO 91
      GAMMAF=1.0
              IF(Z.GT.3.0) GO TO 20
              IF(Z.GE.2.0) GO TO 30
              IF(Z.GT.0.0) GO TO 10
      Z=AMOD(X,1.)
              IF(Z.EQ.0.0) GO TO 90
      Z=X
   10 GAMMAF=GAMMAF/Z
      Z=Z+1.0
              IF(Z.GE.2.0) 30,10
   20 Z=Z-1.0
      GAMMAF=GAMMAF*Z
              IF(Z.GT.3.0) GO TO 20
   30 T=Z-2.
      P=((((((A13*T+A12)*T+A11)*T+A10)*T+A09)*T+A08)*T+A07)*T+A06
      P= (((((P  *T+A05)*T+A04)*T+A03)*T+A02)*T+A01)*T+A00
   80 GAMMAF=GAMMAF*P
      RETURN
   90 PRINT 95,X
      STOP3
   91 PRINT 96,X
      CALL SYSTEMP(0,0,0,0,0,0,1,6LGAMMAF)
      STOP4
   96 FORMAT(*0X = *E20.13* GT 150*)
   95 FORMAT(*0BAD ARGUMENT FOR GAMMAF(Z)*E20.13)
      END
```

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